AN INVESTIGATION ON THE STRATIGRAPHY AND CONTACT RELATIONSHIPS BETWEEN THE MAWSON FORMATION AND THE BEACON SUPERGROUP AT COOMBS HILLS, SOUTH VICTORIA LAND, ANTARCTICA

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ABSTRACT

The Jurassic Mawson Formation is a massive, largely unstratified, pyroclastic tuff breccia that was emplaced by phreatomagmatism. It has an aerial extent (>100 square km) and thickness (>350 m) that are an order of magnitude larger than deposits similar in nature. The contact relationship between this unit and older Beacon strata is poorly understood. The Mawson Formation has been interpreted to be a stratigraphic unit deposited by debris flows (Balance and Watters, 1971), and as an intrusive deposit forming a phreatomagmatic vent complex (White and McClintock, 2001).

Field investigations were performed in the Coombs Hills, south Victoria Land to determine the stratigraphy there, and examine the Beacon – Mawson contact relationship. The sedimentary strata of Coombs Hills have previously been identified as Lashly Formation, Beacon Supergroup, but the specific members have not been reported. Identifying the rock units adjacent to the Mawson tuff breccia is important because it bears directly on the interpretation of the Mawson Formation. Contact relationships were observed at two localities, and six stratigraphic columns were measured in order to determine the stratigraphy.

Lashly Members B, C, and D were identified at Coombs Hills on the basis of section measuring and petrographic analysis. Lashly D was found to have a greater thickness (>250 m) than previously recorded in south Victoria Land. The upper 50 meters of Lashly Member D were found to contain abundant silicic glass shards. The contacts observed at Coombs Hills between the Mawson Formation and the Lashly Formation are intrusive. An estimated 150 m of the Mawson Formation occurs above the

stratigraphically highest Lashly beds. This information suggests a new interpretation concerning the emplacement of the Mawson Formation. The lower part is intrusive as previously suggested. The upper part, which is comprised of at least 150 m, either accumulated stratigraphically as an extra-vent facies, or the additional topography responsible for confining the Mawson Formation as it was emplaced has been eroded away.

ACKNOWLEDGMENTS

I wish to thank my advisor, Dr. David Elliot, for suggesting this project and affording me the opportunity to take part in this research. His everlasting patience, prominent expertise in the field, and continual support in the laboratory and classroom have been greatly appreciated. The knowledge he has energetically conveyed to me throughout the course of my educational tenure at Ohio State is invaluable.

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CHAPTER 1:

INTRODUCTION

1.1 Introduction

This investigation focuses on the volcanic deposits of the Jurassic Mawson Formation, and sedimentary rocks of the Beacon Supergroup at Coombs Hills, which are located west of the Convoy Range (Figure 1.1) in south Victoria Land, Antarctica. The Mawson Formation is Jurassic in age, and consists of predominately unstratified, pyroclastic tuff breccia and lapilli tuff. This formation has an areal extent of 100+ square kilometers, and a thickness of 350+ meters, both of which are an order of magnitude larger than deposits similar in nature to the Mawson Formation. This deposit has been interpreted as stratigraphic (Ballance and Watters, 1971), and as an intrusive deposit forming a phreatomagmatic vent complex (White and McClintock, 2001).

The Lashly Formation, Beacon Supergroup, is reported to crop out at Coombs Hills (Grapes et al., 1974). It is an alluvial sedimentary sequence, with four distinct members. Many sandstones of this formation contain large amounts of volcanic rock fragments, which help to distinguish them from older fluvial deposits. The Lashly Formation comprises the uppermost part of known sedimentary strata in south Victoria Land. Determining the Beacon strata that are present is important because it gives an idea about the paleosurface at the time of Mawson emplacement, and bears directly on the interpretation of the Mawson Formation.

1.2 Purpose of Investigation

The field relationship between the Mawson Formation and older rocks is not well understood. Coombs Hills may contain information about this relationship, however knowledge of the geology there is limited. Therefore, this investigation encompassed two main objectives: 1) Examine the sedimentary sequence at Coombs Hills and identify the rock units present, and 2) Investigate the field relationships between deposits of the Mawson Formation and older sedimentary strata.

1.3 Methodology

1.3.1 Field Investigations

A three person field party comprised of D.H. Elliot, C.B. Grimes, and T.J. Cully visited the Coombs and Allan Hills during the 2002 field season. Field investigations were conducted from 20 November to 17 December, 2002, and included mapping on aerial photographs, the measurement of six stratigraphic sections, and the examination of contact relationships at two separate localities at Coombs Hills. In addition, field observations regarding contact relationships were made at the nearby Allan Hills. Samples of sandstone were collected for petrographic analysis in order to establish the identity of exposed rock units. Mudstone and fine siltstone samples were collected for the purpose of palynological evaluation in order to have a record of the palynomorphs present in the exposed rock units, and facilitate possible age correlations if necessary.

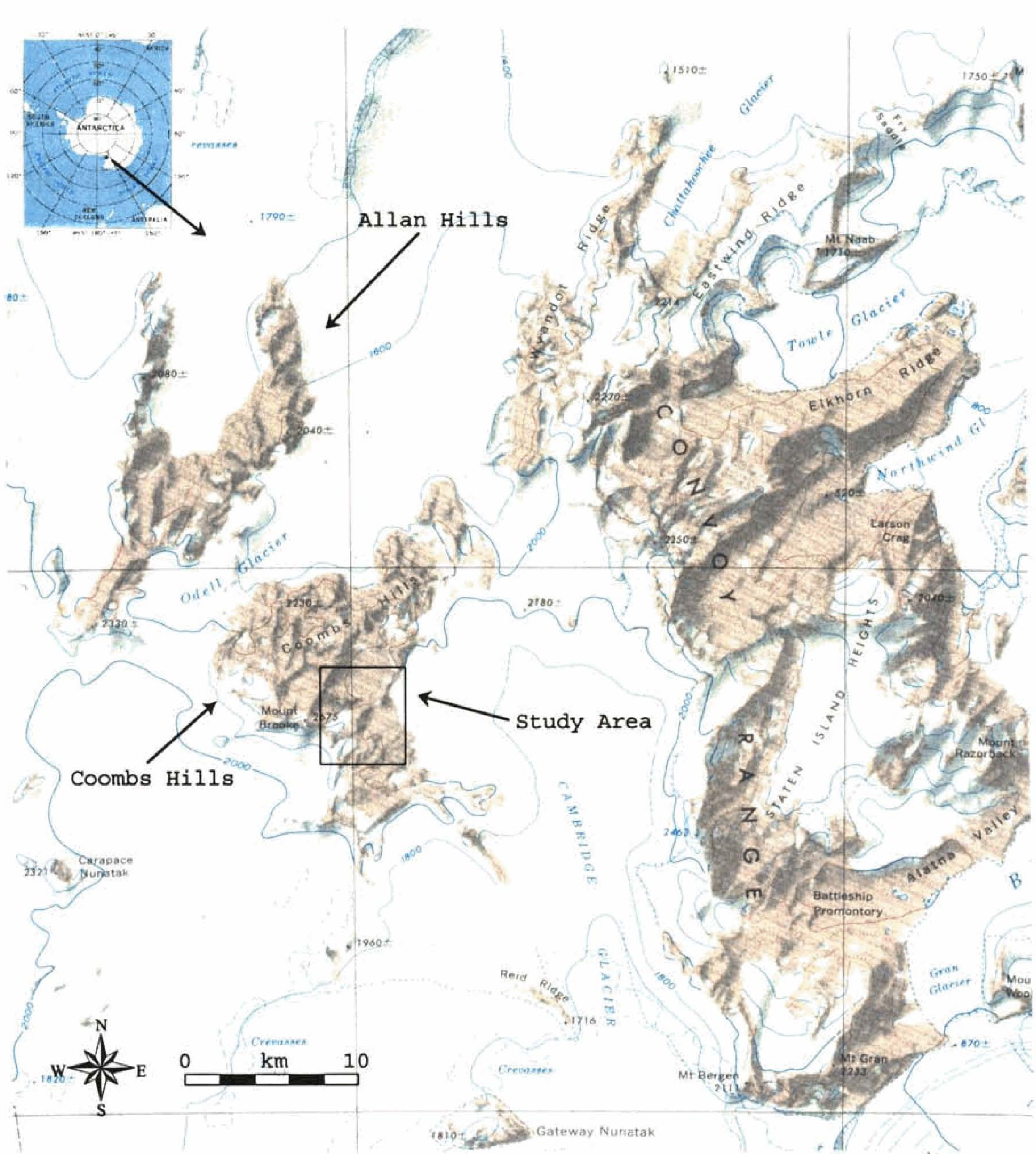

Figure 1.1 Map of the Coombs and Allan Hills, and the Convoy Range in SVL, Antarctica
The 2002 field season study area in Coombs Hills is indicated. Scale is 1:250,000 (adapted from USGS, 1970).

1.3.2 Laboratory Studies

Laboratory studies were conducted from January through May, 2003. Petrographic analysis included thin section preparation and description of 39 samples (Appendix C) collected at Coombs Hills in order to determine the composition of the various members of the Lashly Formation. Those findings were then compared with previous studies to confirm identifications. Stratigraphic columns were constructed and described (Appendices A, B) in detail for all sections measured in the field. A complete sketch map of the study area was compiled, using information obtained during this field season and observations made during previous expeditions by D. H. Elliot (pers. comm.) (Figure 1.2).

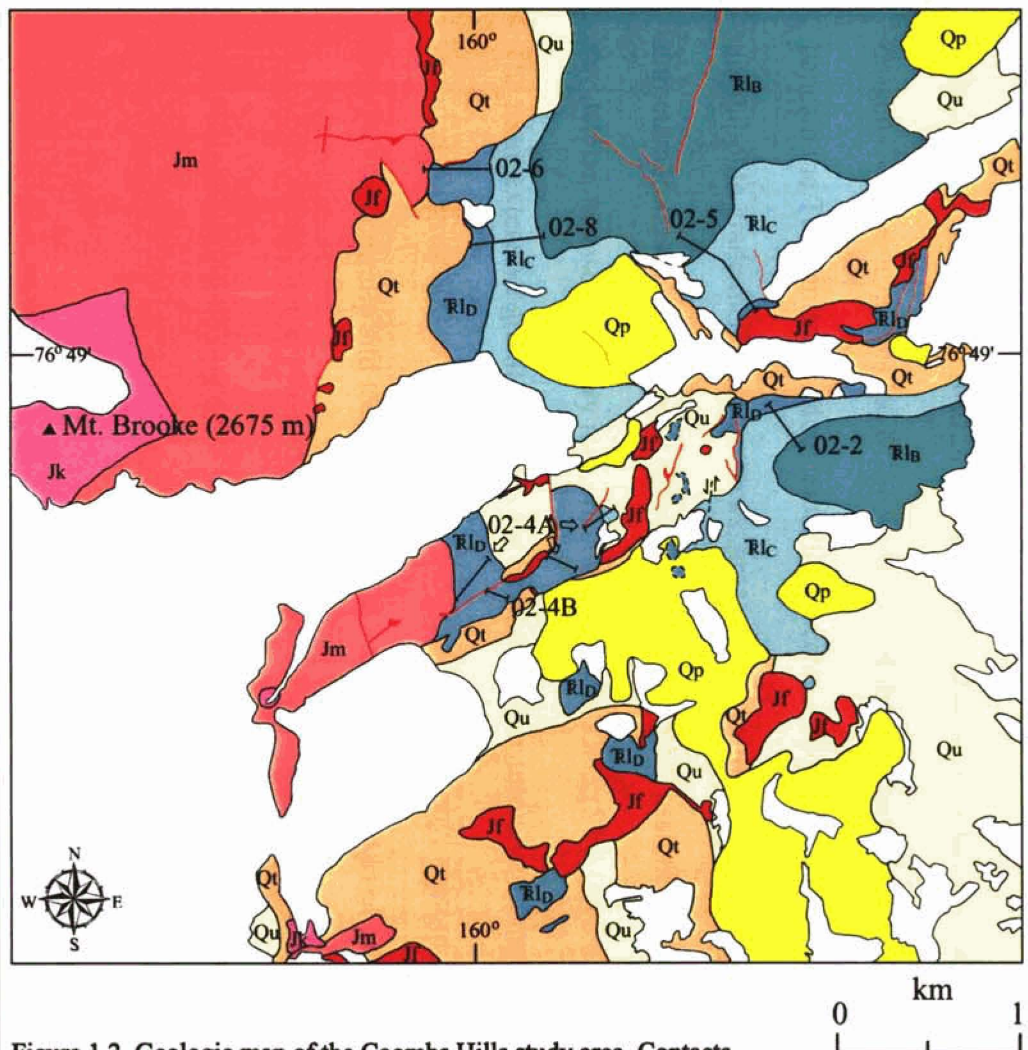

Figure 1.2 Geologic map of the Coombs Hills study area. Contacts were mapped using observations in the vicinity of measured sections, and vertical aerial photographs. Map adapted from aerial photograph flight line TMA-2495-V; frame no. 019. Approximate scale: 1:40,000

CHAPTER 2:

REGIONAL GEOLOGY

The information contained in this chapter is largely from Collinson et al. (1994). Information obtained from other sources is referenced as such.

The Transantarctic Mountains form a continuous belt along the western edge of the Ross Sea, and extend to the Weddell Sea as a series of isolated peaks (Figure 2.1). This belt separates East and West Antarctica, and is located along the Panthalassan margin of the East Antarctic craton, which was formerly a convergent plate boundary. This margin experienced two episodes of compressive tectonism since the Proterozoic; first the Late Proterozoic Beardmore orogeny, and later the Cambro-Ordovician Ross orogeny. These orogenies led to the formation of the basement rocks presently found beneath the Transantarctic Mountains, which consist of pre-Devonian sub-greenschist to amphibolite grade metamorphic rocks, granitoid batholiths and plutons, and some unmetamorphosed clastic rocks. Gunn and Warren (1962) assigned Cambrian to Ordovician metasedimentary rocks in south Victoria Land (SVL) to the Skelton Group. The more extensive granitoids form the Granite Harbor Intrusive Complex, which was intruded between 500 to 450 Ma. Following the Ross orogeny, most of this region remained structurally and tectonically undisturbed. The early part of this passive period allowed for extensive erosion and denudation, and the formation of a pre-Devonian regional unconformity known as the Kukri Peneplain (Gunn and Warren, 1962). This erosion surface cut across the plutonic and metamorphic roots of the Ross orogenic belt.

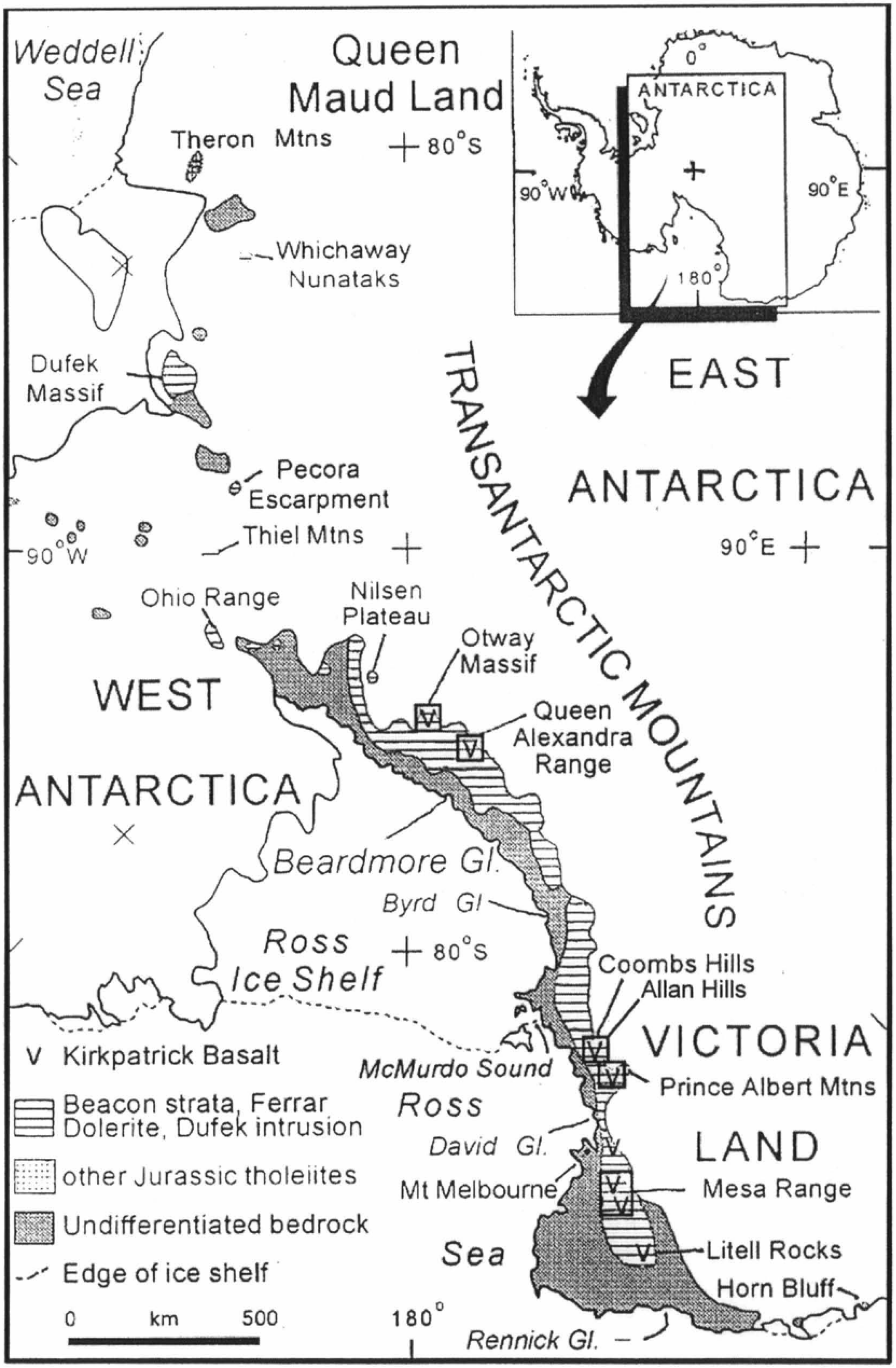

Figure 2.1 General map of the Transantarctic Mountains region of Antarctica (from Elliot and Hanson, 2001).

Predominately fluvial sedimentary strata of the Beacon Supergroup (Figure 2.2) lie above the Kukri Peneplain, and are divided into the Devonian Taylor Group, and the Permian-Triassic Victoria Group. The Taylor Group consists of a 1400 meter thick sequence of quartzose sandstone, siltstone, and mudstone. Such a large thickness appears to be confined to southern Victoria Land; the Taylor Group is absent north of the Convoy Range, and varies from 0 to 300 meters in other parts of the Transantarctic Mountains. Trace fossil assemblages from the Taylor Group indicate a facies change from marine to alluvial deposition near the middle of the sequence. Following this period of sedimentation, continental scale glaciation developed across much of Gondwanaland, resulting in Upper Carboniferous (?) to Lower Permian glacial deposits resting unconformably above the Taylor Group.

In SVL, the base of the Victoria Group consists of the Darwin and Metschel Tillites, which are preserved only as valley fill deposits up to 80 meter thick. These formations pinch out to zero thickness in places, due to a post-glacial erosional episode that was enhanced by isostatic rebound. The Lower to Upper Permian Weller Formation overlies the glacial deposits. It consists of quartzose sandstone, shale, carbonaceous mudstone, and thick coal beds, indicating a period of global warming following the end of continental glaciation. In the Allan Hills, these coal measures appear to have been deposited by meandering streams, coarsening up into braided stream deposits. Macro and microfossils of the *Glossopteris* flora are common in the fine grained carbonaceous beds of this unit. Upper Permian deposits are absent from Victoria Land, being represented by a ferruginous paleosol between the Permian coal measures and Triassic sandstones. The Early Triassic Feather Formation overlies the Weller Formation. The Feather Formation consists of a 175 to 250 meter thick braided stream deposit of coarse to pebbly sandstones. The upper portion consists of finer sandstones and ferruginous paleosols, and has been separated as the Fleming Member.

Permian and Early Triassic Victoria Group deposits located in the central Transantarctic Mountains were deposited in a foreland basin setting. Strata in SVL of the same age were deposited in an intra-cratonic basin. These two basins were separated by a basement rock foreswell called the Ross High. Therefore, basement source rocks on either side of the intra-cratonic basin supplied sediment for infilling, while the foreland basin had a volcanic source. Development of a fold belt along the Panthalassan margin in the Late Permian eventually caused a change in the depositional setting of Victoria Land. Distal volcanism and uplift enhanced erosion and led to infilling of the foreland basin. By the Middle Triassic, foreland basin deposition had superceded the intra-cratonic basin, which caused an influx of volcanic detritus into the SVL intra-cratonic basin. This influx is observed in the Triassic Lashly Formation.

The Lashly Formation (Middle to Late Triassic) is approximately 430 to 520 meter thick, and is subdivided into 4 members. Lashly A is a 50 to 70 meter thick unit comprised of fining upward cycles of medium- to fine-grained volcaniclastic sandstone, and greenish grey siltstone and mudstone with abundant root horizons. It is interpreted as a braided stream and flood-plain deposit. Member B of the Lashly Formation is a 50 to 60 meter thick sequence of medium- to fine-grained, trough cross-bedded sandstones indicative of braided stream deposits. These sandstones also contain blocks of silicified peat and logs in the Allan Hills. Lashly C is a 50 to?130 meter thick unit of fining upward sequences of volcaniclastic sandstone, siltstone, shale, carbonaceous mudstone, and thin coal beds. The *Dicroidium* flora commonly occurs in finer grained carbonaceous beds of this unit. This unit is interpreted as a meandering stream deposit.

Lashly D has a maximum reported thickness of 220 meters (Askin et al., 1971), consisting largely of medium- to coarse-grained quartzose sandstones at the base, but with some fining upward cycles of medium sandstone, siltstone, and mudstone in the upper portion. Preserved thickness variations of Victoria Group strata are common due to a reported regional unconformity with 500 meters of relief locally (Collinson et al., 1983).

An Early Jurassic hiatus followed deposition of the Lashly Formation, but was terminated by Jurassic tholeitic magmatism associated with the breakup of Gondwanaland. Dolerite dikes and sills from the Ferrar Dolerite intrude much of the sedimentary strata throughout SVL. Volcanic tuff breccia and lapilli tuff of the Mawson Formation have been reported to have a thickness of nearly 400 meters (Bradshaw, 1987). The Mawson Formation has been interpreted as lahar deposits resting diconformably on older Beacon strata (Ballance and Watters, 1971), and as phreatomagmatic deposits originating from multiple vents (White and McClintock, 2001). Kirkpatrick Basalt lavas up to 250 meters thick lie conformably on the Mawson Formation (Elliot and Hanson, 2001). Uplift to form the Transantarctic Mountains of today began in the Cretaceous, and continued episodically into the Late Cenozoic.

Group	AGE	ROCK UNIT	DESCRIPTION	MAX. THICKNESS (METRES)
BEACON SUPER-GROUP / VICTORIA GROUP	TRIASSIC	LASHLY FM Member D	Sandstone like Member B.	520+
		LASHLY FM Member C	Interbedded fine sandstone, siltstone and thin coal beds. *Dicroidium*.	
		LASHLY FM Member B	Massive feldspathic and lithic sandstone with a few logs and stems.	
		LASHLY FM Member A	Greenish-grey fine sandstone, siltstone and claystone in fining-upwards cycles. Abundant roots and a few calamitid stems.	
		FEATHER CONGLOMERATE Upper part	Quartzose grit, sandstone and siltstone in fining-upwards cycles.	100
	PERMIAN	FEATHER CONGLOMERATE Lower part	Quartzose sandstone and grit with abundant white vein quartz pebbles south of Taylor Glacier. Mainly sandstone to north.	150
		WELLER COAL MEASURES	Quartzose and feldspathic sandstone and minor carbonaceous shale. Pebbles and boulders scattered and in lenses especially near base. Coal, logs and stems and *Glossopteris*.	250
			PYRAMID EROSION SURFACE	
		METSCHEL TILLITE	Tillite, with scattered mainly granitic clasts up to 1.4 m across. Minor sandstone, siltstone, conglomerate.	70
			MAYA EROSION SURFACE	
BEACON SUPER-GROUP / TAYLOR GROUP	MID-UPPER DEVONIAN	AZTEC SILTSTONE	Greyish-red and greenish-grey siltstone and light coloured sandstone. Fish fossils, plant roots, mud-cracks and ripplemarks common. Rare plant stems.	220
	DEVONIAN AND OLDER(?)	BEACON HEIGHTS ORTHOQUARTZITE	Orthoquartzite, with occasional quartz grit lenses. Rare lycopod stems. *Beaconites* trails throughout.	220
		ARENA SANDSTONE	Yellowish-grey sandstone. Ferruginous layers, burrows and trails (including *Beaconites*) common.	360
		ALTAR MOUNTAIN FM	Sandstone, siltstone. Burrows and trails (including *Beaconites*).	240
		Odin Arkose	Arkosic grit and conglomerate.	(50)
			HEIMDALL EROSION SURFACE	
		NEW MOUNTAIN SANDSTONE	Quartzose sandstone, minor siltstone.	270
		Terra Cotta Siltstone	Shaly siltstone, minor sandstone	(60)
		Boreas Subgreywacke	Argillite, sandstone, conglomerate	(20)
		Windy Gully Sandstone	Pebbly quartzose sandstone	(50)
	ORDOVICIAN TO PRECAMBRIAN	BASEMENT COMPLEX	KUKRI SURFACE	

Figure 2.2 Stratigraphy of the Beacon Super-Group in SVL (from Barrett and Kohn, 1975).

CHAPTER 3:

PREVIOUS WORK AT ALLAN AND COOMBS HILLS

3.1 Allan Hills

3.1.1 *Beacon Supergroup*

Initial investigations in the Allan Hills region were performed by Gunn and Warren (1962), who reported outcrops of the Beacon Supergroup and Mawson Tillite. Beacon strata were mapped and described by Ballance (1977), and Collinson et al. (1983). Rock units exposed consist of the Permian Weller Formation, and the Triassic Feather Formation and Lashly Formation (Ballance, 1977; Collinson et al., 1983). The upper 70 to 80 meters of the Weller Formation make up the lowest exposed stratigraphic unit, and consists of fining upward cycles of quartz sandstones, micaceous and carbonaceous siltstones, and coal seams up to 2 meters thick. Macro and microfossils of the *Glossopteris* flora are present (Ballance, 1977; Collinson et al., 1983). Ballance (1977) recognized and named the Fiestmantel Member in the lowest part of the exposed Weller Formation. This member has a maximum thickness of 30 m, and reportedly lacks the fining upward sequences and coal beds found higher in the formation, but does contain leaves of the *Glossopteris* flora. This member, designated as a local member of the Weller Formation, was not reported by Collinson et al. (1983). A well developed paleosol separates the Weller Formation from the overlying Feather Formation. Early

Triassic microfossils were reported in the upper part of the Feather Formation (Collinson et al., 1983). Ballance (1977) reported a thickness of approximately 300 meters for the Feather Formation, but Collinson et al. (1983) only reports 193 meters, including the upper 53 meters that make up the Fleming Member. The Lashly Formation (325 meters thick) conformably overlies the Feather Formation (Collinson et al., 1983). All 4 members of the Lashly Formation crop out; Member A (49 meters), Member B (54 meters), Member C (137 meters), and Member D (85 meters), with *Dicroidium* macro and microfossils being recorded in the upper two members (Collinson et al., 1983).

3.1.2 *Mawson Formation*

The Mawson Formation has been described by Gunn and Warren (1962), Ballance et al. (1965), Borns and Hall (1969), Ballance and Watters (1971), and Grapes et al. (1974). They reported unusually large thicknesses (>300 meters). The Mawson Formation (formerly the Mawson Tillite of Gunn and Warren, 1962) has been reported to be of volcanic origin, possibly a debris flow deposit (Ballance et al., 1965; Borns and Hall, 1969). Steeply dipping contacts between the Mawson Formation and Beacon strata have been interpreted to represent margins of the vents from which the debris flows erupted (Ballance and Watters, 1971). Stratification within the Mawson Formation has also been observed at Allan Hills, indicating surficial accumulation (Gunn and Warren, 1962; Borns and Hall, 1969; Ballance and Watters, 1971). Grapes et al. (1974) discussed the likelihood that the Mawson Formation resulted from phreatomagmatism associated with the emplacement of dolerite into water-rich systems in Beacon strata.

3.2 Coombs Hills

The first geologic map of Coombs Hills was published by Grapes et al. (1974). Outcrops of the Lashly Formation and Mawson Formation were reported. Intrusive contacts between the Mawson Formation and Beacon strata have been reported by White and McClintock (2001). Bradshaw (1987) and Elliot and Hanson (2001) reported evidence of crude layering within the Mawson Formation. As much as 392 meters of Mawson Formation has been recorded at Mt. Brooke, Coombs Hills (Elliot and Hanson, 2001).

3.2.1 *Lashly Formation*

The Lashly Formation was originally described and named by McElroy (1969). The presence of four distinguishable units was later noted by Barrett et al. (1971) following observations made in SVL. Sections measured on Horseshoe Mountain, Mt. Dearborn, South Robison Peak, and Mt. Bastion formed the basis for these subdivisions. Barrett et al. (1971) reported a lower cyclic unit of medium to fine volcaniclastic sandstones, siltstones, and grey to greenish mudstones with root traces, a massive, cross-bedded, log bearing sandstone unit, another cyclic unit of medium to fine volcaniclastic sandstone, siltstone, carbonaceous mudstone, and coal, bearing abundant *Dicroidium* leaves, and finally another massive, cross-bedded, quartz-rich sandstone unit. The first three units were reported to have thicknesses generally between 70 to 90 meters (Barrett et al., 1971). The uppermost, youngest massive sandstone unit had a maximum reported thickness of 220 meters on Mt. Bastion (Askin et al., 1971). These units were later designated as the individual Members A, B, C, and D (Barrett and Kohn, 1975).

CHAPTER 4:

STRATIGRAPHY OF THE LASHLY FORMATION AT COOMBS HILLS

4.1 Stratigraphy

Beacon Supergroup rocks of the Triassic Lashly Formation were first mapped, but not described, at Coombs Hills by Grapes et al. (1974). No further studies were conducted up until this investigation. During the 2002 field season, six stratigraphic sections were measured and described (Appendix A and B) in detail in order to determine the rock units underlying the Mawson Formation more specifically. As a result, three of the four members of the Lashly Formation were identified. Tuffaceous strata in the uppermost beds of what is here described as Lashly D, were also observed, and may be correlative to the Hanson Formation of the central Transantarctic Mountains (Elliot, 1996).

4.1.1 *Member B*

Lashly B occurs as large sandstone platforms forming the lowermost strata exposed at Coombs Hills (Figure 4.1). A thickness of 14 meters was recorded at the base of locality 5, however because of lack of outcrop the maximum thickness is not known. This unit consists of light grey to yellowish orange, medium grained sandstone consisting

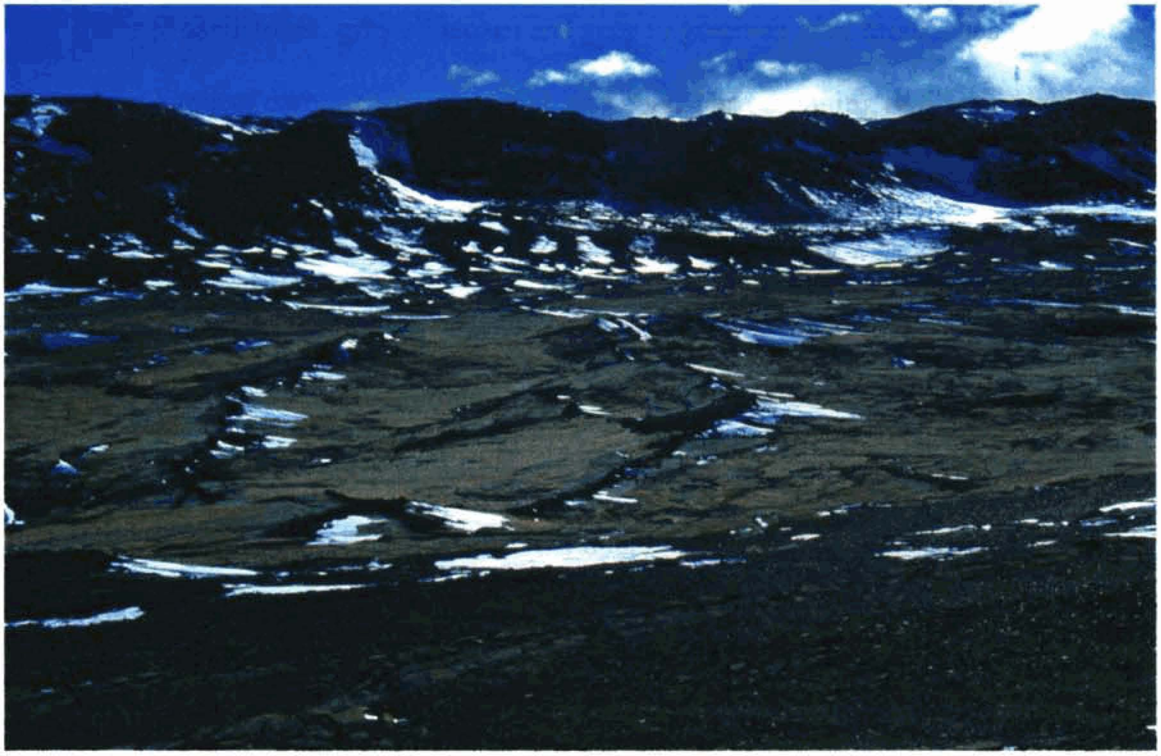

Figure 4.1 Photo illustrating a large platform that is characteristic of the upper part of Lashly B. Differential weathering and the formation of an undulating surface may be caused by cross-bedding, or the intrusion of dolerite dikes. This platform is located at the north-east corner of the field area (Figure 1.2).

of quartz, lithic fragments, rose quartz, mica, and minor feldspar. Well developed trough cross-bedding, with sets on the order of 20 to 50 centimeters, and ripple cross lamination occur in this unit. Lashly B has little to no carbonaceous debris, but fossilized fragments of wood are common. Small, pustular bodies less than 1 centimeter in diameter were observed sporadically, and in very low abundances as compared with Members C and D.

4.1.2 *Member C*

The influx of carbonaceous material marks the contact between Lashly C and Lashly B (Figure 4.2). Lashly C is cyclic, with fining upward sequences of medium to fine volcanic sandstones, grey siltstones and grey to greenish grey mudstones with varying amounts of carbonaceous material, and coal. The beginning of a new cycle is represented by a sandstone ledge commonly less than 1.5 meters thick and infilling shallow scours in the underlying strata. Sandstones are light grey with a greenish tint, and contain abundant amounts of quartz, lithic fragments, and mica. Ripple cross lamination and small-scale trough cross-bedding are common, with sets between 5 and 30 centimeters. The cycle continues into grey siltstones and mudstones. Carbonaceous material becomes more abundant toward the upper part; light grey mudstone beds grade into dark grey mudstone, followed by coaly mudstones and coal. Individual cycles have a maximum thickness of 11 meters, and commonly range from 2 to 6 meters. Coal is

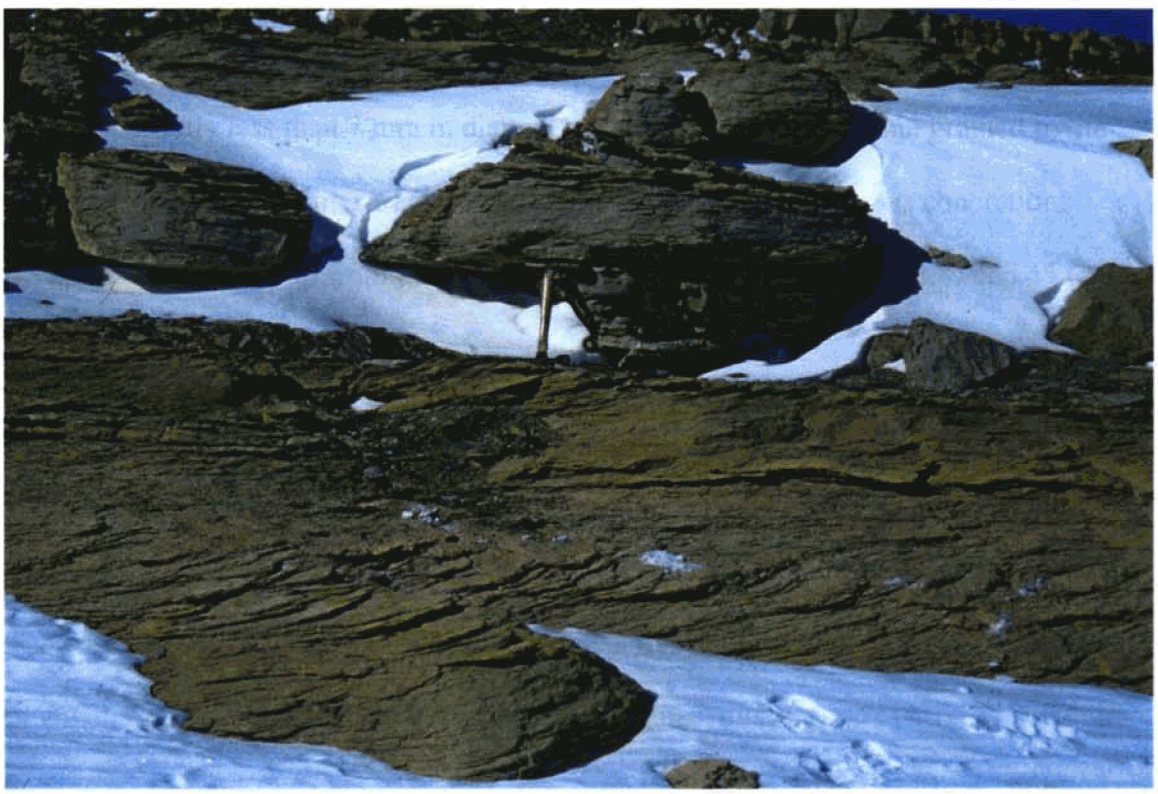

Figure 4.2 Contact between Lashly Members B and C on section 02-5, marked by the base of the hammer. Hammer is approximately 30 centimeters tall.

occasionally absent from the cycle, but can also be relatively thick. Thickness ranges from 2 to 80 centimeters (normally less than 10 centimeters thick). Horizons containing abundant plant megafossils can often be found adjacent to coal beds (Figure 4.3). Particularly abundant are leaves of the *Dicroidium* flora, including *D. odontopteroides*. Other plant fragments and fossil logs occur as well. Well preserved, vertical burrows are common in the mudstones beneath the sandstone ledges (Figure 4.4). One burrow has a diameter of 2 centimeters, and is 35 centimeters long, but most are generally thinner and less than 10 centimeters long.

Sandstone beds of this unit contain variable abundances of small pustular bodies, as well as ferruginous concretions. Pustular concretions can occur individually, but generally occur with zones in which abundant pustules are distributed. Pustules are spherical, with a diameter of 0.5 to 1.5 centimeters. Ferruginous concretions are well rounded, usually less than 7 mm in diameter, and consist mostly of fine grained pyrite with an oxidized outer rim. A horizon containing abundant ferruginous concretions occurs at 30.0 meters up from the base of section 2. Member C ranges between 45 to 65 meters, with an average thickness of approximately 58 meters.

4.1.3 *Member D*

The base of Lashly D commonly, but not invariably, can be recognized by the presence of angular mudstone and siltstone clasts set in a coarse, quartz sand matrix. This feature is known as a mud-flake breccia, and forms from the rip-up and re-deposition of older fine-grained strata by erosional processes. The maximum thickness observed for this

Figure 4.3 Thick coal bed approximately 60 centimeters thick. Beneath the coal is a horizon of abundant plant megafossils, including *Dicroidium* flora. Geologist for scale. Section 02-5, 21.0 m.

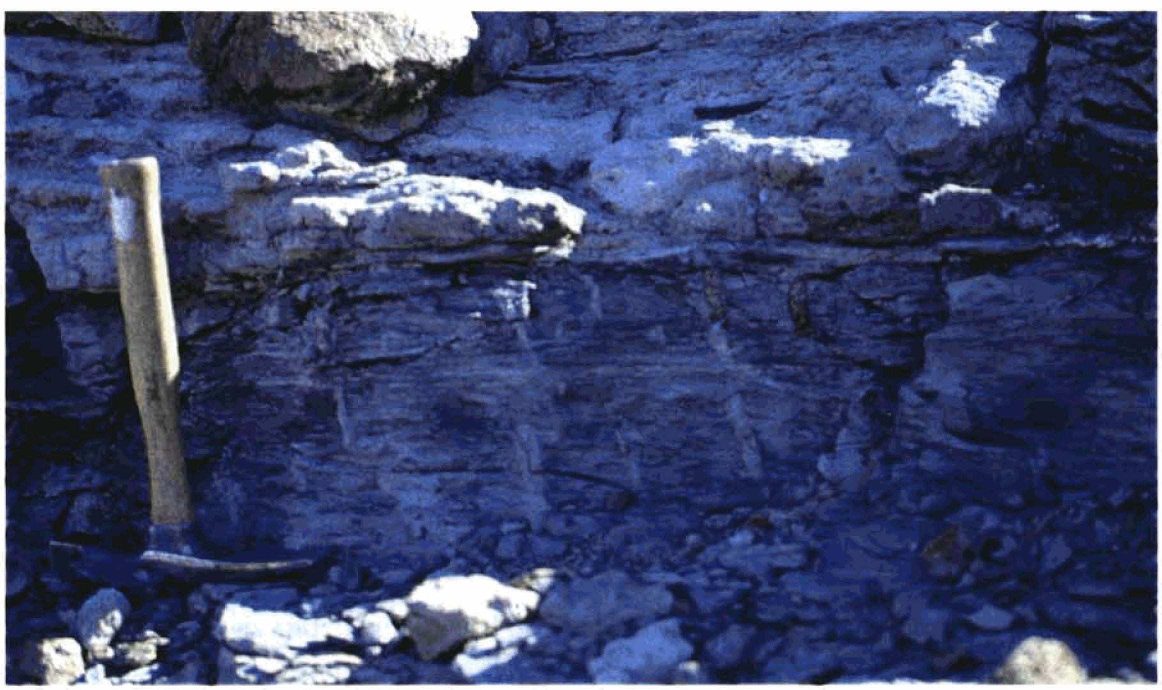

Figure 4.4 Large, vertical burrows in Lashly C mudstone beds. Hammer for scale. Section 02-2, 24.8 m.

basal unit is 1.2 meters. Above the base, Lashly D consists of coarse, light grey to yellowish-orange, trough cross-bedded (sets from 40 to 100 centimeters), quartzose sandstone.

This sandstone consists mostly of quartz, with minor amounts of rose quartz, lithic fragments, red garnet, feldspar, and mica, all weakly cemented by clays. Massive bluffs and steep slopes up to 56 meters thick occur in the lower part of this member. The coarse sandstone passes up into medium to fine grained sandstone ledges ranging from 30 centimeters to 6 meters thick, separated by thinly bedded siltstone and grey mudstone beds that contain minor carbonaceous material. Fining upward sequences, which include the rocks in between the base of one sandstone ledge to the next, average approximately 10 meters in thickness. Plant stems and rare leaf fragments of the ?*Dicroidium* flora are present in the carbonaceous beds. The upper interval of Lashly D is still quite sandy, but fine sandstone, siltstone and mudstone beds become more common. Exposure of the uppermost beds is very poor, but the rocks appear to be cyclic, fining upward sequences: thin sandstone ledges are separated by covered intervals in which small, light and dark grey mud flakes can be brought to the surface.

Sandstones of Lashly D commonly contain pustular concretions similar to those found in Member C. These pustules occur as spherical bodies less than 1.5 centimeters in diameter, as well as elongate, tabular bodies up to 2.4 centimeters long. Zones of poorly to unstratified sandstone near the top of section 6, and in sections 4A and 4B, are composed almost entirely of these pustular concretions. At the top section 6, an 11 meter thick, discontinuous and disrupted bed of silicic tuff marks the upper limit of Lashly D sandstone. Ash bearing, fine grained sandstone and siltstone are abundant in at least the upper 47 meters of Lashly D at locality 4A, but poor exposure makes this interval impossible to describe in detail. The occurrence of these tuffaceous beds may be indicative of a separate, younger unit above Lashly D. In places where the top of Lashly D is not currently an erosion surface, thicknesses of 109 meters, and 250 meters were recorded.

4.2 Post-Depositional Features

Sandstone and coal dikes crosscut bedding of Member C, along with less common dolerite and tuff breccia sills. Sandstone dikes are generally thin, 1 to 40 centimeters, and coarse grained to pebbly. Coal dikes were observed as thin extensions that appear squeezed up from underlying coal beds (Figure 4.5). In one case coal is associated with tuff breccia in a dike that is approximately 25 centimeters thick. Funnel-shaped phreatic pipes also occur. These are intrusive, brecciated pipes comprised of sedimentary fragments in a sand matrix that are the result of steam explosions. Sandstone beds of Member C contain variable abundances of the small pustular bodies, as well as ferruginous concretions. The pustular concretions formed as a result of crystallization by a secondary mineral (zeolite). The ferruginous concretions are indicative of influence by groundwater. The zone in section 2 composed of abundant ferruginous concretions may mark a horizon along which abundant groundwater was flowing.

Dolerite dikes from 1 to 7.5 m thick intrude parts of Lashly D. Intervals of sections 4A, 4B, and 6 were observed to consist of coarse, poorly stratified sandstone with intermittent pods of dolerite (Figure 4.6). The occurrence of small pustular bodies

Figure 4.5 Coal dike forming from thin, underlying coal bed in Lashly C. Remobilization of coal and sand resulted from phreatic activity incurred by intrusions of the Ferrar Dolerite. Hammer for scale. Section 02-2.

(a few centimeters in diameter) is often closely associated with intruding dikes. They are present throughout much of the unit, but become extremely abundant in sandstones adjacent to dolerite intrusions. Near the top of section 6, these pustular bodies make up most of predominately unstratified sandstone. These bodies are believed to have formed secondarily as a result of phreatic activity, leading to the crystallization of zeolite and calcite. On section 4A, a 60 cm thick sandstone dike containing fragments of siltstone, mudstone, and coaly debris was observed. This dike crosscuts existing strata, trending east-northeast up the hillside.

Immediately underlying the Mawson Formation is the uppermost member of the Lashly Formation. The contact between the Mawson and Lashly Formations is exposed at two localities. At locality 4A, a steeply dipping, intrusive contact was observed between tuff breccia and sandstone. The contact at locality 6 is uncertain, because the rocks there are tilted and disturbed. Many of the sandstones adjacent to the contact are largely unstratified and contain abundant pustular concretions, indicating disturbance by phreatic activity. Nevertheless, the simplest interpretation is that the contact is again intrusive.

Figure 4.6 Deformation of Lashly D sandstone has resulted from the emplacement of pods of Ferrar Dolerite and associated phreatic activity. The bluff forming the ridgeline stands approximately 7 meters, and contains abundant pustular concretions. Section 4A, 131m.

CHAPTER 5:

PETROGRAPHY

5.1 Introduction

The examination and description of 38 thin section samples was conducted to determine the composition of the exposed rock units of the Lashly Formation at Coombs Hills. Full petrographic descriptions are given in Appendix C. Samples consist of litharenites, sublitharenites, lithic subarkoses, tuffaceous litharenites, and one mudstone. This chapter provides a summary of the petrographic analysis, and discusses the mineral and lithic components, as well as secondary matrix and cement. Detrital matrix appears to have been replaced, apart from original phyllosilicates, in many of these samples, and is commonly very fine grained. Therefore, the matrix and cement are described together with secondary components unless otherwise noted. Characteristics of the three observed members of the Lashly Formation are described separately in ascending stratigraphic order. The prefix 02 is dropped from all samples in this chapter i.e. sample 2-9 can be found under sample 02-2-9 in Appendix C.

5.2 Lashly B

Only one sample was examined from Lashly B, a litharenite (sample 2-1). This sandstone is medium-grained (0.25 to 0.4 mm) with detrital grains of quartz, feldspar, mica, amphibole, garnet, zircon, and lithic fragments. Quartz and lithic rock fragments are found in approximately equal abundances. Quartz contains aligned and unaligned inclusions of zircon and mica. Quartz overgrowths and irregular grain boundaries are common. Feldspar grains include plagioclase (composition An_{29}), and microcline. Lithic fragments include dominant volcanic fragments, common metamorphic rock fragments, and minor sedimentary rock fragments. Secondary matrix is pervasive in this sample, consisting mostly of zeolite, clays and phyllosilicate, and minor calcite. Grains are often partially replaced by zeolite and calcite.

5.3 Lashly C

Fifteen samples were examined in thin section from Lashly C. These sandstones are poorly sorted, very fine- to medium-grained (0.1 to 0.4 mm) litharenites (Figure 5.1). One sample is a coarse-grained (0.75 to 2.0 mm) sublitharenite (sample 2-37). Detrital grains are dominated by quartz and lithic fragments, with variable amounts of mica, feldspar, chert, zircon, garnet, apatite, and tourmaline. The matrix consists of clay/phyllosilicate, calcite, zeolite, and carbonaceous material.

Mineral Grains

Quartz grains are predominately monocrystalline, subangular to subrounded, and invariably have irregular grain boundaries. Undulose extinction in grains is dominant, but grains with straight extinction can be common. Straight edge grain boundaries and sutured margins are common in adjacent grains, and grains may exhibit dark rims outlining the original grain, due to the incorporation of opaques by formation of overgrowths. Inclusions of apatite, zircon, and mica in quartz are rare. The percentage of quartz ranges from 17 to 44%, with an average of 26%. Mica includes biotite, muscovite, and chlorite. Biotite is by far the most abundant, and occurs as long, thin flakes, or as rectangular flakes. Biotite flakes commonly are compacted and/or altered; they have pale yellow to red-brown pleochroism, may appear very dirty or weathered, and cleavage is usually distorted. Muscovite occurs as colorless, long, thin flakes. When measured along their long axes, biotite and muscovite are commonly the largest grains in a sample. Chlorite shows pale green to green pleochroism, and wavy cleavage. Mica commonly accounts for less than 6%, but three samples have mica content of 8 to 13% (2-9, 2-19,

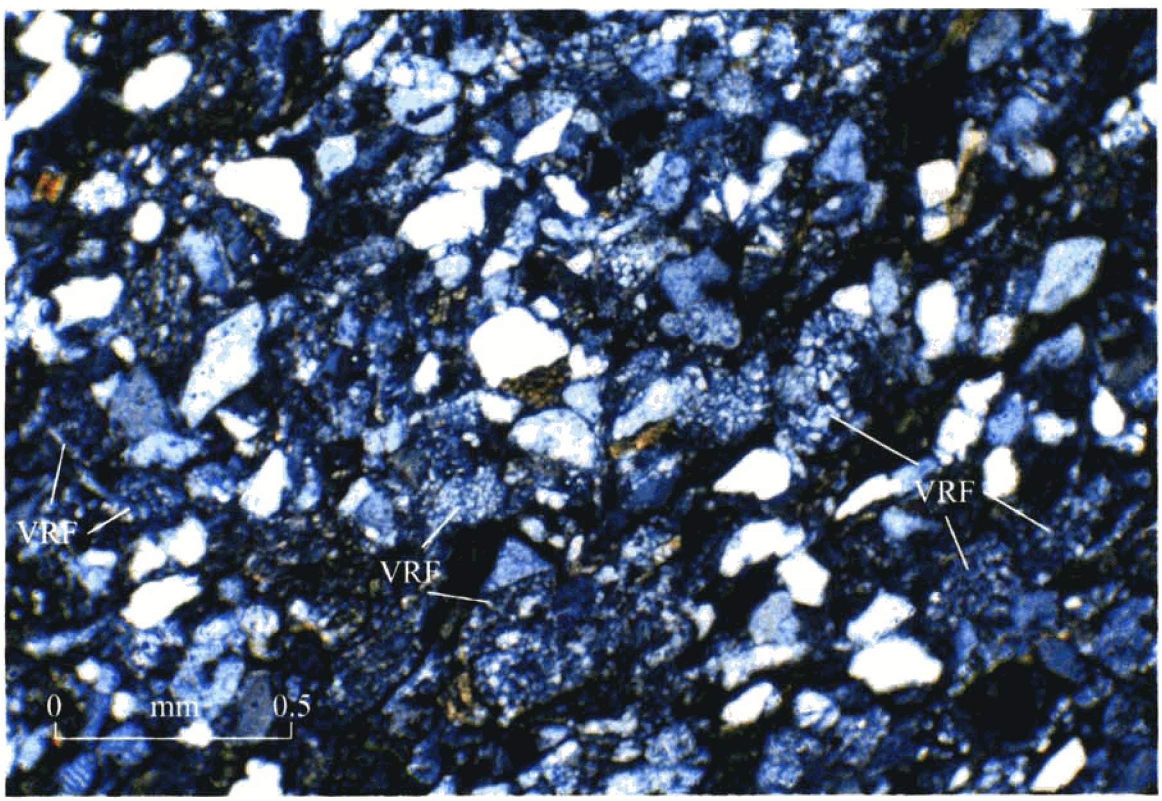

Figure 5.1 Photomicrograph of sample 02-5-20 with crossed polars, showing the nature of Lashly Member C sandstone. Note the abundance of volcanic rock fragments (VRF), a few of which are marked. 4x magnification.

2-23). Feldspars include plagioclase, microcline, and microperthite. Plagioclase grains exhibit albite and rare Carlsbad-albite twinning. The composition ranges from An_{25} to An_{32}, with an average composition of An_{29}. Microcline is distinguished by the presence of coarse crosshatch twinning. Microperthite exhibits exsolution lamellae, indicating the separation into two varieties of feldspar. An unidentified ?feldspar sparsely occurs with an altered, isotropic core (?zeolite), and a rim with low birefringence. The abundances of microcline and microperthite are similar, but overall feldspar is not very common in these samples. Cherty fragments (possibly altered volcanic fragments rather than true chert) are very fine- to medium-grained (grains less than 0.04 mm), and uncommon. Amphibole was identified only in sample 5-1; it occurs as angular, broken, greenish brown grains with good cleavage, and is identified as hornblende.

Heavy minerals include zircon, garnet, apatite, and tourmaline. The abundances of these minerals relative to each other are given in Table 5.1. Zircon occurs as colorless rounded grains, subangular fragments, or rarely as elongate prisms. Garnet occurs as light pink to light grey angular fragments. Apatite occurs as rounded grains or as short, stubby prisms. Tourmaline grains are subangular.

Lithic Fragments

Lithic fragments include volcanic, metamorphic, and sedimentary rock fragments. Volcanic fragments are separated into three types, which vary from felsic, to intermediate-felsic in composition. These fragments are generally very fine grained, making specific identifications extremely difficult. Abundance of volcanic and metamorphic fragments relative to one another is given in Table 5.2.

Lashly Formation	Sample	Heavy Minerals					
		Gt	Zr	Ap	Tm	Amph	Sp
Member B	02-2-1	R	C	R?		R	
Member C	02-2-9	-	C				
	02-2-19	R	R		R		
	02-2-23		-				
	02-2-28	R	C	R	R		
	02-2-37	R	R?				
	02-2-39	-	-				
	02-2-40	-	R				
	02-4-1	C	A	R	R		
	02-5-1	C	R	R	R	R	
	02-5-4	-	C	C	R		
	02-5-8	R	C				
	02-5-12	C	C	C	R		
	02-5-15	R	R	C	R		
	02-5-20	R	A		C		
	02-8-6	-	R	R			
Member D	02-3-2	C	R		R		
	02-4-10	C	-	R		R	
	02-4-13	A	R				
	02-4-20	A	C				
	02-4-27						
	02-4-29	-	R	R			
	02-4-30					R	R
	02-4-32					R	C
	02-4B-1	-	R		R		
	02-4B-4	C	R		R	R	
	02-4B-6	-	R	R			
	02-4B-9	A	C		C	R	
	02-5-22	A	-		R		
	02-5-23	A	C		R		
	02-6-1						
	02-6-5						
	02-6-6						
	02-7-5						
	02-7-6	R	C			R?	
	02-8-15	A	R		R		
	02-8-16	-	R				
	02-8-19	C	C	R	R		

Table 5.1 Relative abundances of accessory minerals in the Lashly Formation at Coombs Hills. A = Abundant; C = Common; R = Rare. Gt = Garnet; Zr = Zircon; Ap = Apatite; Tm = Tourmaline; Amph = Amphibole; Sp = Sphene.

Type 1, the most dominant volcanic fragment, is characterized by porphyritic and aphanitic grains with a cryptocrystalline siliceous matrix (Figure 5.2). These fragments are dusty to dirty, and greyish-brown to pale yellow in plane light. Microlites consist dominantly of quartz, and trace small opaque grains. Porphyritic grains contain sparse phenocrysts of quartz up to 0.25 mm, and often lack or contain only small amounts of phyllosilicate. Aphanitic grains commonly have varying amounts of phyllosilicate alteration, which helps distinguish them from microcrystalline or very fine-grained chert. Composition of these rock fragments is most likely dacite to rhyolite. Type 2 volcanic fragments (Figure 5.3) are much less common, and are recorded in only seven samples (2-19, 2-39, 5-1, 5-8, 5-15, 5-20, 8-6). These grains are trachytic or pilotaxitic, with a cryptocrystalline matrix. Microlites of plagioclase feldspar dominate, but may include rare quartz and opaques. Type 2 fragments usually lack any phyllosilicate alteration. Their composition is intermediate to felsic. Type 3 volcanic fragments (Figure 5.4) are relatively common, though less abundant than Type 1. Type 3 consists of porphyritic to aphanitic grains with microlites of plagioclase feldspar and quartz, in a hypocrystalline or cryptocrystalline matrix. The presence of plagioclase distinguishes Type 3 from Type 1. Grains appear dirty pale brown in plane light. These grains consist of either abundant non-trachytic plagioclase feldspar with minor quartz and sparse opaque grains, or abundant quartz with sparse plagioclase phenocrysts and trace opaques. Porphyritic grains have sparse phenocrysts up to 0.16 mm, predominately of plagioclase but also of quartz. Phyllosilicate alteration is common in these grains in varying abundances, but can be lacking. Composition is intermediate to felsic. Together, volcanic fragments make up an average of 17.6% of Lashly C samples.

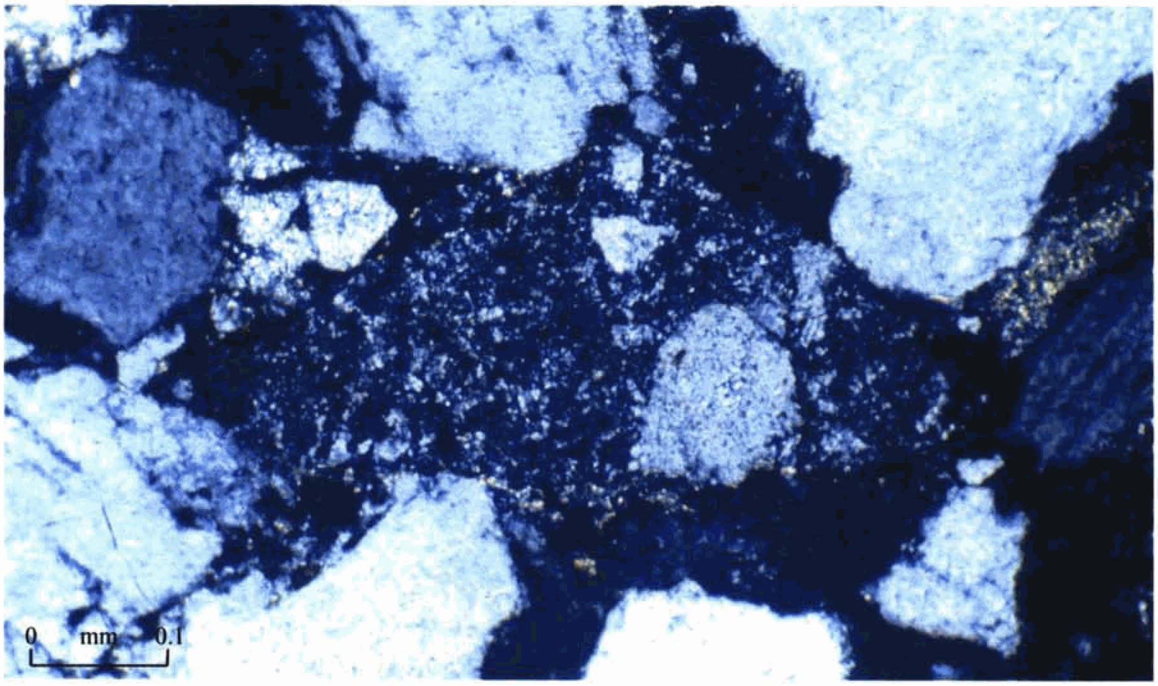

Figure 5.2 Photomicrograph of sample 02-4-13 with crossed polars, showing Type 1 volcanic rock fragment with a large quartz phenocryst. 10x magnification.

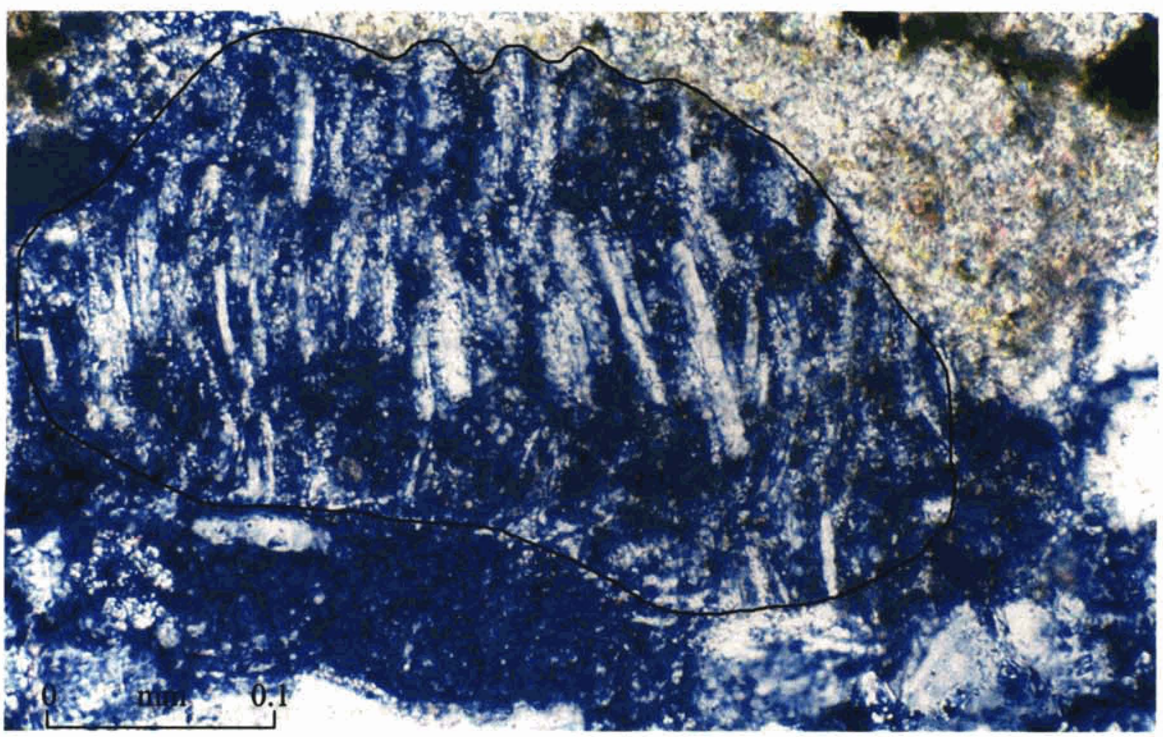

Figure 5.3 Photomicrograph of sample 02-8-6 with crossed polars, illustrating Type 2 volcanic rock fragments (outlined), with trachytic texture. 25x magnification.

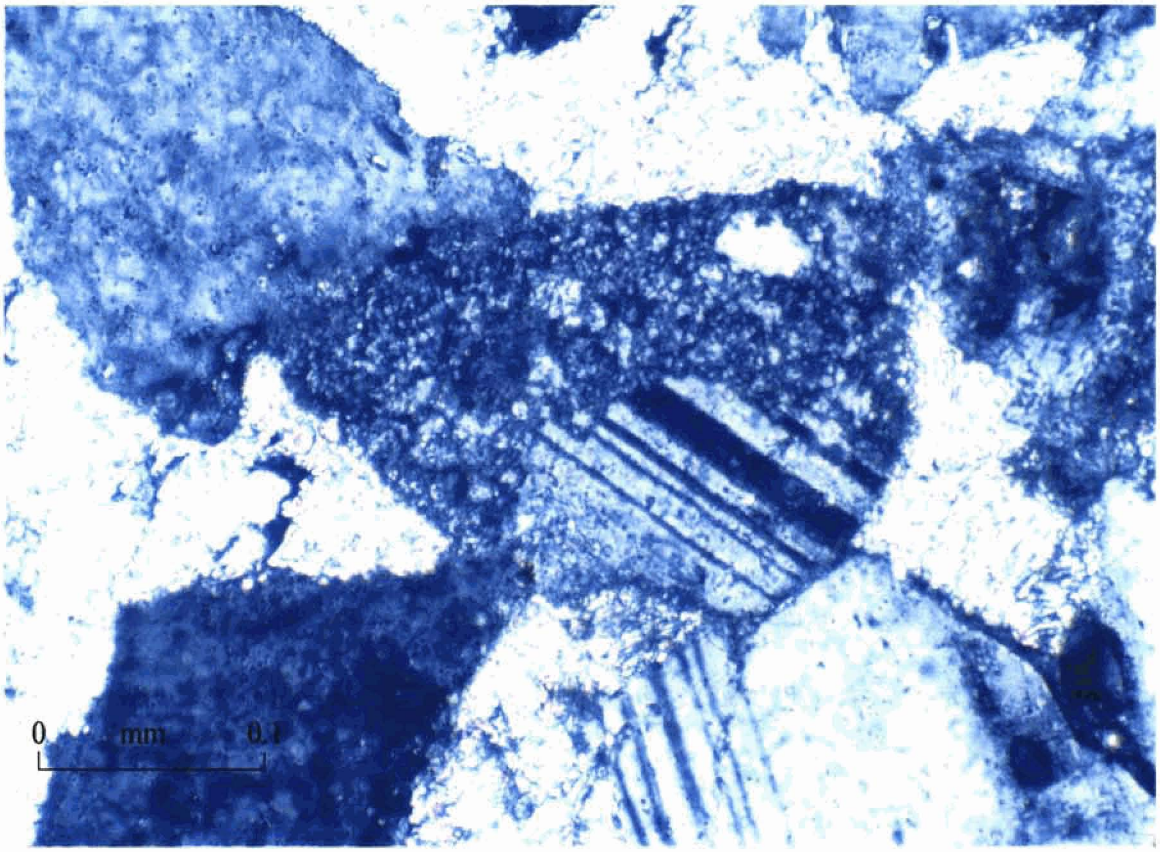

Figure 5.4 Photomicrograph of sample 02-8-15 with crossed polars, showing Type 3 volcanic rock fragment containing a large plagioclase phenocryst. Material with high birefringence is calcite. 25x magnification.

Metamorphic fragments are most common in samples collected near the base and top of Lashly C. Samples in the middle contain 0 to 2%, as compared with 3 to 4% for those collected near the top and bottom. Metamorphic fragments consist of low grade metasedimentary schist fragments. Schistose fragments are foliated and contain quartz and mica. Quartz can be flattened or stretched out, and aligned, or it can be rounded. Brown, white, and greenish mica are very abundant, and show poor to predominately excellent alignment within the fragments.

Sedimentary fragments consist of yellow-brown, subangular to moderately rounded clasts of mudstone to very fine sandstone. Fine grained clasts contain clay-sized particles. Coarser-grained fragments contain grains up to 0.08 mm. Fragments in sample 2-19 are as large as 4.5 mm, but they are much smaller in all other samples.

Matrix

Primary

Fine grained phyllosilicate and carbonaceous material occurs in many of these samples, and may be detrital material. Recognizable phyllosilicates included biotite and sericite. Carbonaceous material consists of black, irregular masses or as long stringers. It often appears brownish and blurred in crossed polars. Most samples contain at least minor carbonaceous material, and in six samples it is abundant (> 2%) (2-39, 2-40, 5-4, 5-12, 5-15, 5-20).

Secondary

Secondary clay minerals are abundant in some samples, but their origin is uncertain. They are difficult to distinguish from original detrital fine-grained phyllosilicates. Matrix material that is not identifiable as sericite or biotite is considered to consist of clays. Many grains exhibit a complex matrix cement of secondary calcite and zeolite. Calcite is recorded in six of the seven samples from section 2, and occurs as patchy pore space filling. Isolated patches not connected in the plane of the thin section commonly extinguish together. Calcite may occur as the dominant cement component, or as a minor constituent in combination with other matrix material. It is often observed replacing other grains, especially quartz, contributing the irregular nature of the grain boundary that is common in quartz. Two types of zeolite were observed in three samples (2-39, 2-40, 5-1). Some rare ?zeolite grains have extremely weak birefringence, and are difficult to identify. The easily recognized zeolite is identified as laumontite, because it has first order yellow birefringence and good cleavage, and may replace plagioclase. It is especially abundant in sample 5-1. The other type of zeolite has tentatively been identified as analcite. The average matrix percent of these samples is 38%, which is more than the typical pore volume of detrital sediment, suggesting that replacement has indeed occurred.

Secondary quartz overgrowths on quartz grains are very common. Straight edge grain boundaries, sutured margins, irregular grain boundaries, and dark rims are observed at least in part in every sample. Overgrowths on quartz are invariably in continuity with the original grain. In some instances, quartz overgrowths act as cement in combination with other matrix minerals. Chalcedony is uncommon, but is observed filling fractures in some thin sections.

5.4 Lashly D

Twenty-one sandstone samples, and one mudstone (4B-1), were examined in thin section from Lashly D. The sandstones consist of moderate to poorly sorted, medium- to very coarse-grained (0.25 to 1.75 mm) sublitharenites, lithic subarkoses, tuffaceous litharenites, and litharenites (Figure 5.5). Six samples contain tuffaceous material in the form of glass shards and possibly ash, and are fine grained (4B-6, 4-29, 4-30, 4-32, 7-5, 7-6). Detrital grains consist predominantly of quartz, with variable amounts of feldspar, lithic fragments, mica, amphibole, pyroxene, chert, garnet, zircon, tourmaline, apatite and sphene. Matrix consists of clays/phyllosilicates, calcite, zeolite, and silica.

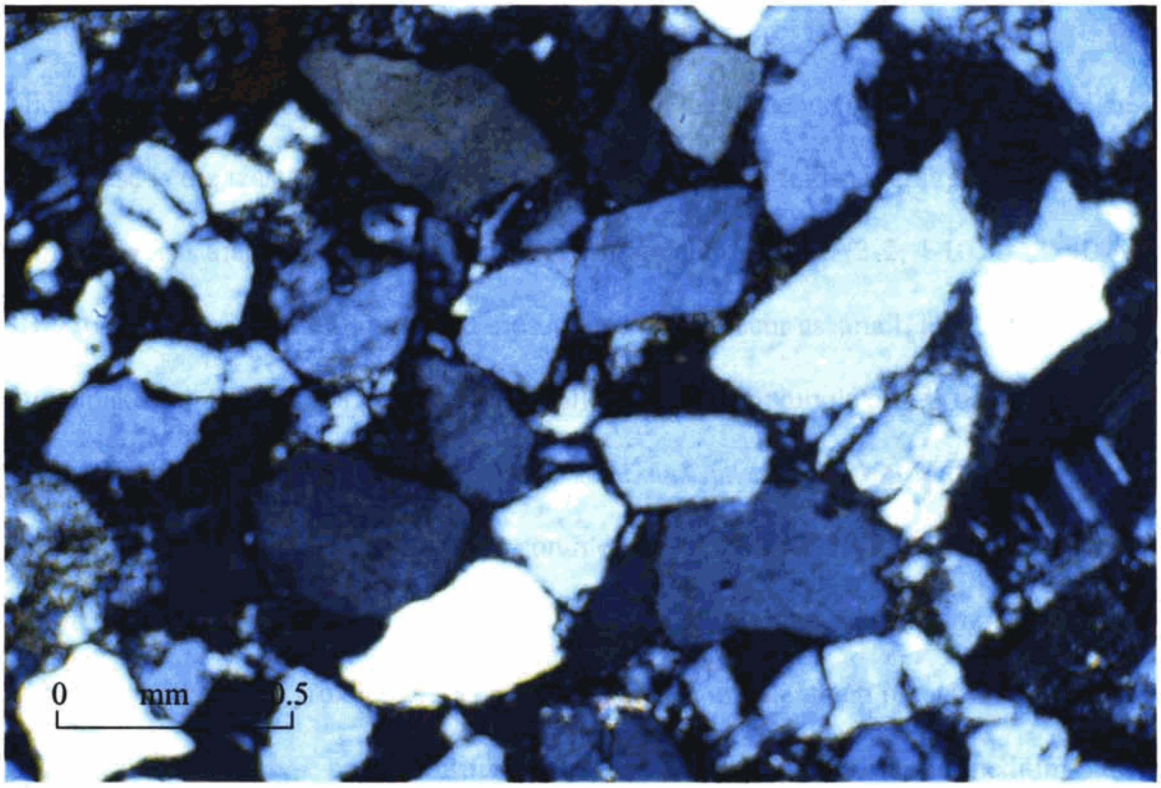

Figure 5.5 Photomicrograph of sample 02-4-13 under crossed polars, showing the nature of Lashly Member D sandstone. Nearly all grains in the field of view are quartz. 4x magnitude.

Mineral Grains

Quartz grains are predominantly monocrystalline, though large polycrystalline grains do occur sparsely in samples 4-13, 4-20, 4-27, and 4B-4. Grains are subangular to moderately rounded, with irregular grain boundaries, and have extensive quartz overgrowths. Undulose extinction is more common than straight extinction. Inclusions of mica, apatite, and zircon are uncommon. Quartz makes up an average of 42% of non-tuffaceous samples, and 12% of tuffaceous samples. Feldspar consists of plagioclase, microcline, microperthite, and orthoclase. Plagioclase grains exhibit albite twinning. Composition ranges from An_{27} to An_{31}, with an average composition of An_{29}. Plagioclase in tuffaceous samples has an average composition of An_{35}. Plagioclase is commonly the dominant feldspar. Microcline is differentiated by coarse, crosshatch twinning. Microperthite is less abundant, and is recognized by the presence of exsolution lamellae. Orthoclase is the least common feldspar observed. The total feldspar content is commonly less than 5%, but six samples contain greater than 7% (3-2, 4-10, 4-13, 4B-4, 4B-9, 6-6). Mica includes biotite and muscovite, which occur as small, long, thin flakes. Mica makes up less than or equal to 4% of all samples. Amphibole grains occur sparsely as angular, broken fragments with good cleavage, and have been identified as hornblende. Hornblende becomes more common in samples 4-30 and 4-32. Occurrence of pyroxene is restricted to single grains in very few samples, except in sample 4-32 where it is common. Pyroxene grains have pale brown to pale green pleochroism, show good cleavage, and have been identified as augite. Chert occurs as fine- to medium-grained subrounded grains, and is uncommon.

Heavy minerals include garnet, zircon, tourmaline, apatite, and sphene. Relative abundances are given in Table 5.1. Garnet is the most common, and occurs as light pink to light grey fragments that can be as large as 0.52 mm. Garnet can be quite abundant, and makes up nearly a full 1% of several samples. Zircon occurs as small, rounded to oval-shaped grains. Tourmaline occurs as subangular to rounded grains. Apatite occurs as rounded grains, or rarely as stubby prisms. Sphene is exceedingly uncommon, and its occurrence is restricted to two tuffaceous litharenites (4-30, 4-32). Grains are angular, and slightly elongate.

Lashly Formation	Sample	Lithics Fragments				
		Type 1	Type 2	Type 3	Meta	Gs
Member B	02-2-1	A		A	C	
	02-2-9	C		U	U	
	02-2-19	A	R	C	U	
	02-2-23	C		C	R	
	02-2-28	A		C		
	02-2-37	U		U	R	
	02-2-39	A	R	U	U	
Member	02-2-40	A		C	R	
C	02-4-1	A		U		
	02-5-1	C	R	C	R	
	02-5-4	A		U		
	02-5-8	A	U	C		
	02-5-12	A		C	U	
	02-5-15	A	R	C	U	
	02-5-20	A	R	C	U	
	02-8-6	A	U	C	C	
	02-3-2	C			U	
	02-4-10	C		U	U	
	02-4-13	C	R	U	U	
	02-4-20	U	R	U	U	
	02-4-27	U	R		U	
	02-4-29					A
	02-4-30	R			R	A
	02-4-32	C	R	U	C	C
	02-4B-1					
Member	02-4B-4	U	R	U	C	
D	02-4B-6			R		A
	02-4B-9	C	R	U	R	
	02-5-22	C	R	U	U	
	02-5-23	C		R	U	
	02-6-1	U		R	U	
	02-6-5	C			U	
	02-6-6	U		R	R	
	02-7-5	R			R	A
	02-7-6				R	A
	02-8-15	C	R	U	U	
	02-8-16	C	R	R	U	
	02-8-19	C	R	U	C	

Table 5.2 Content of volcanic and metamorphic rock fragments in sandstones from the Lashly Formation. Samples are grouped by the member and locality from which they were collected. A = Abundant (> 10%); C = Common (5 - 10%); U = Uncommon (2 - 4%); R = Rare (< 2%). Meta = metamorphic lithic fragments; Gs = glass shards.

Lithics

Lithic fragments include volcanic, metamorphic, and sedimentary rock fragments, glass shards, and pumice. Abundance of lithic fragments is given in Table 5.2. Volcanic fragments have the same composition as those of Lashly C. Type 1 are the most common volcanic rock fragment. Type 2 volcanic fragments are identified in only half of the samples examined for Lashly D, and occur sparsely. Type 3 volcanic fragments are common, but much less so than Type 1. Volcanic fragments collectively make up an average of 5.7% of Lashly D samples. Metamorphic fragments are metasedimentary schists as in Lashly C. Abundance has little variability throughout the examined samples, and is generally 2 to 5%. Sedimentary fragments consist of mudstone to siltstone, and are uncommon. Glass shards occur in 6 samples (4-29, 4-30, 4-32, 4B-6, 7-5, 7-6). These are long, thin, very angular, glassy fragments. Shards are isotropic, and appear tan to light brown in plane light. Occasionally they exhibit a curved shape or are tricuspate, indicating formation by disintegrating vesicular magma. Glass fragments are invariably rimmed with fine-grained mica that is colorless and has high birefringence (sericite?). Shards generally have a much greater length than width; they are from 0.08 to 0.2 mm long. Glass shards are the dominant constituent of nearly all the samples in which they occur. The average content of glass shards in these six samples is 24%. Pumice occurs in only one sample (4B-6), and is sparse. Pumice fragments are subrounded, pale grey, with abundant vesicles that have been infilled by secondary matrix. Vesicles are set in a network of isotropic, glassy material. Fragments have an average size of 0.15 mm.

Matrix

Primary

Fine-grained phyllosilicate, ash, and rare carbonaceous material occur in samples from Lashly D, likely as detrital material. Phyllosilicates include biotite and sericite. Tuffaceous samples have ash in addition to primary phyllosilicates. The matrix of tuffaceous samples averages 55% of the thin section. Much of this matrix is extremely fine-grained and irresolvable, and has been interpreted as volcanic ash. Carbonaceous material occurs rarely, as irregular, black to brown masses.

Secondary

Secondary matrix consists of clays, calcite, and zeolite. Clay matrix is fine-grained, and difficult to distinguish from detrital phyllosilicate and ash. Therefore, as in Lashly C, matrix material that is not identified as phyllosilicate, or as ash, is interpreted to consist of clays. Calcite occurs as large well developed masses that extinguish together over several millimeters, or as patchy pore space filling. Calcite makes up nearly the entire matrix of three samples (6-1, 8-15, 8-16), and occurs sparsely in others. Replacement by calcite is extensive, indicated by irregular contacts with detrital grains (Figure 5.6). Zeolite occurs in four samples (4-13, 4-32, 4B-4, 6-6). At least two types are present. Laumontite is easily recognized by its first order yellow birefringence, and good cleavage. The other type has very weak birefringence, and has been tentatively identified as analcite. A third type of zeolite may also be present. This type has first order grey birefringence, and one subparallel-parallel parting that may be cleavage. These characteristics suggest that this is stilbite.

Quartz overgrowths are quite extensive in samples from Lashly D, and are commonly a significant component of the matrix cement. Substantial authigenic silica cement occurs in eight samples (4-10, 4-13, 4B-4, 4B-6, 4B-9, 5-22, 6-6, 8-19).

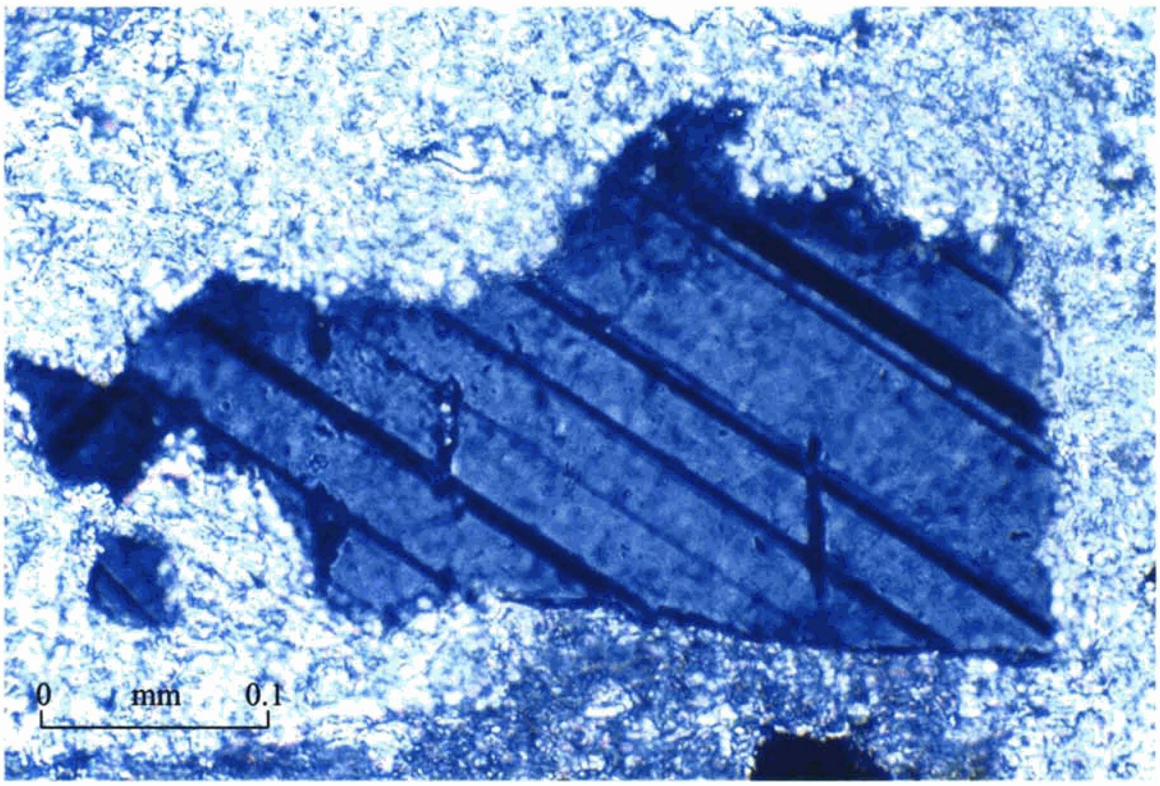

Figure 5.6 Photomicrograph of sample 02-8-16 under crossed polars, showing the ragged boundary of a large plagioclase grain. The plagioclase is undergoing replacement by secondary calcite cement. 25x magnification.

CHAPTER 6:

DISCUSSION

6.1 Introduction

Fluvial sedimentary rocks of the Triassic Lashly Formation, Beacon Supergroup, crop out in the central Coombs Hills. A marked change in the lithofacies of these deposits occurs twice in the exposed stratigraphy, distinguishing three of the four informal members of the Lashly Formation. Sandstones in the lower two observed units contain abundant intermediate-felsic volcanic detritus. The upper unit contains significantly less volcanic material until the uppermost 50 meters, in which tuffaceous material is observed. More than 350 meters of poorly to unstratified tuff breccia of the Mawson Formation also occur at Coombs Hills, with a relationship to older Beacon strata that is intrusive.

6.2 Stratigraphy

The stratigraphy of the Lashly Formation has been described by several workers including Askin et al. (1971), Barrett and Kohn (1975), Ballance (1977), and Collinson et al. (1983). Four informal members have been designated as a result. Lashly Member A is 60 to 90 meters thick. It consists of alternating sandstone and mudstone beds, and has root horizons. Lashly Member B consists of quartz rich, trough cross-bedded, channeled sandstone with occasional thin mudstone beds, and contains wood fragments. This member is reported to be about 70 to 100 meters thick. Lashly C is decribed as cyclic sequences of sandstone, carbonaceous siltstone and mudstone, and coal. The sandstones contain abundant volcanic detritus, and the *Dicroidium* flora has been reported in carbonaceous beds. Member C is about 70 to 100 meters thick. Member D is massive, coarse to pebbly, cross-bedded, quartzose sandstone similar to Member B. A maximum thickness of 220 meters (Askin et al., 1971) is reported, but the top contact of Member D is commonly either erosional, or with dolerite intrusions.

Rock outcrops at Coombs Hills strongly correlate to the upper three members of the Lashly Formation. The stratigraphically lowest outcrop consists of massive, trough cross-bedded, platform forming sandstone, which also contains fragments of silicified wood. Only the top of this member is observed, but the lithology is consistent with Lashly Member B. Overlying this sandstone is a unit like Lashly C, with cyclic sequences of sandstone, carbonaceous siltstone and mudstone, and thin coal beds. Several horizons were found to contain plant megafossils of the *Dicroidium* flora, and the sandstones contain abundant lithic fragments. The average thickness at Coombs Hills is about 60 meters, which is comparable to thicknesses observed elsewhere. The third unit observed at Coombs Hills is massive, coarse to pebbly, cross-bedded sandstone, which changes up section to a cyclic sequence with sandstone, siltstone, and mudstone. The basal part of this unit is the same as described for Lashly D. The upper part of Lashly D differs from other outcrops of this member. The thickness of this unit is 250.8 meters, which is greater than previously recorded for Lashly D.

6.3 Depositional setting

Fining upward sequences, small scale cross-bedding, and the presence of carbonaceous material and coal indicates a fluvial origin for the sedimentary strata at Coombs Hills. The exposed top of Lashly B consists of medium-grained, cross-bedded, channel sandstone that contains occasional log fragments. These findings are consistent with those of Collinson et al. (1983), who interpreted Member B as a sandy, low sinuosity, braided stream deposit. The massive sandstone platforms of Lashly B change to the cyclic sequences of Lashly C, which contain thin sandstone ledges, carbonaceous siltstone and mudstone, and coal. Plant megafossils are also common. Fining upward sequences, plant megafossils, and coal suggest Lashly C was deposited by high sinuosity, frequently migrating meandering streams (Ballance, 1977; Collinson et al., 1983). The mudstone and carbonaceous beds suggest swampy condition, and may have been deposited on an adjacent flood plain or from the infilling of abandoned stream channels. Plant megafossils, stems, and burrows are common in the mudstone and coaly beds underlying sandstone ledges, indicating periods of stability and biologic activity between migrations of a channel across the area.

At Coombs Hills, the base of Lashly D consists of mud rip-up clasts suspended in coarse to pebbly sandstone. The increase in grain size, and incorporation of mud clasts up to 15 centimeters long, indicates an increase in the paleocurrent energy from the coal bearing sequence below. Lashly D fines slightly to a medium- to coarse-grained, massive sandstone, which forms a basal bluff up to about 50 meters thick. Thin siltstone and mudstone beds come in above this, and become more abundant towards the top of the unit. These characteristics are consistent with reports on Lashly D. Lashly D is not as well preserved throughout SVL, and enough sedimentological data has not been obtained previously to interpret the depositional setting (Collinson et al., 1994). Characteristics at Coombs Hills suggest that the lower part of Lashly D was deposited by low sinuosity, multi-channeled braided streams, similar to Lashly B. The upper part of Lashly D appears to represent development of higher sinuosity streams and flood plain deposits.

The collection of paleocurrent data was not a focus of this investigation, but reconnaissance observations were generally consistent with the work of Barrett and Kohn (1975), Ballance (1977), and Collinson et al. (1983). They reported north-northwest flow directions for the Lashly Formation.

6.4 Petrography and provenance

One thin section was examined from the top of Member B of the Lashly Formation. Aside from being slightly more quartz-rich (38%), this sample is much like those from Lashly C in that it is fine- to medium-grained, and contains abundant volcanic lithic fragments. Petrographic changes between Lashly C and D are quite evident. Member C is less well sorted and contains large amounts of volcanic lithic fragments, whereas Member D is coarser grained and more quartz-rich. Member C also contains carbonaceous debris, which is rare higher in the Lashly Formation. Both members show affects of secondary alteration, which has been interpreted to be the result of phreatomagmatism and contact metamorphism associated with Ferrar volcanism (Grapes et al., 1974; Korsch, 1974; Ballance and Watters, 2002).

Quartz is dominant throughout the sequence as monocrystalline grains with undulose extinction. Lashly C contains only slightly more quartz (26%) than lithic fragments, whereas Lashly D is much more quartzose (42%). Feldspar content increases in the upper part of the Lashly Formation. Plagioclase is dominant in Lashly C, and abundance remains fairly consistent throughout the sequence. Potassium feldspar content increases in Lashly D, with microcline as the dominant feldspar. This contrasts with Korsch (1974), who reported orthoclase as the dominant feldspar in Victoria Group sandstones. Feldspar content increases enough by Lashly D that compositions include lithic subarkoses.

Heavy minerals include garnet, zircon, tourmaline, apatite, and sphene. Lashly C commonly contains garnet, zircon, and tourmaline. Lashly D contains predominantly garnet and tourmaline, with lesser amounts of zircon and apatite. Garnet fragments make up to 1% of Lashly D thin sections, and fragments can be up to 0.52 mm. This contrasts Ballance (1977), who reported apatite to be the dominant heavy mineral of the Lashly Formation. Sphene occurs in only the two uppermost samples collected in Lashly D.

Samples throughout the sequence invariably contain volcanic lithic fragments that are intermediate-felsic to felsic in composition. Lashly C, on average, contains 17%. These volcanic fragments are dominated by silicic grains that commonly contain quartz phenocrysts in a cryptocrystalline groundmass. Fragments containing randomly oriented or aligned plagioclase are also present throughout the sequence, but commonly in trace amounts. Intermediate-acid volcanic fragments were also reported in the Lashly Formation by Korsch (1974). Thin sections from Lashly D contain volcanic fragments of the same composition, but they are much less abundant than samples from lower in the

Lashly Formation. These samples have an average content of volcanic fragments less than 6%.

Volcanic glass shards appear in the uppermost part of Lashly Member D. This is the first time glass shards have been reported in the Lashly Formation. Six samples were collected from thin, very fine sandstone ledges along the upper part of two sections, and found to contain abundant volcanic glass shards. These shards are brown, glassy, angular fragments with shapes typical of silicic shards. They occur with quartz and other mineral grains, but their angularity and fairly unaltered character suggest that they were transported only a short distance. Tuffaceous sandstones have also been reported in the central Transantarctic Mountains in the lower Jurassic Hanson Formation (Elliot, 1996). Based on initial petrographic data, the ash bearing sandstones at the top of Lashly D may be an equivalent of the Hanson Formation. No obvious stratigraphic break was observed and the exact relationship of the ash-bearing beds to Lashly D sandstones is uncertain. The occurrence of fresh volcanic ash indicates the onset of silicic volcanism, possibly related to either very early Ferrar magmatism, or to a distinct and unrelated episode of silicic magmatism.

A large percentage of the sand making up the Lashly Formation was derived from quartz rich basement rocks (Ballance, 1977). A low grade metasedimentary source is also apparent throughout the formation. Lashly Member C contains a large amount of intermediate-felsic volcanic detritus that indicates an influx of detritus derived from a volcanic terrain. A direct volcanic source is not known. This volcanism probably also contributed much of the plagioclase that occurs throughout Members C and D (Korsch, 1974). The decrease of volcanic fragments in Lashly D, along with the increasing abundance of microcline and quartz suggest the return of a felsic plutonic source, probably the Precambrian basement. The uppermost 50 meters of Member D are diluted by abundant silicic glass shards that were likely supplied by fairly proximal contemporaneous volcanism.

The paragenesis of secondary mineralization that occurs in Beacon sandstones has been reported in detail by Ballance and Watters (2002). Several of the alteration characteristics in their report were also observed here. Compaction of detrital micas is very common in mica-rich samples of Lashly C. Calcite cement occurs in all three members, but Member D samples show much more extensive replacement, with calcite making up more than 50% of several thin sections. Zeolite was also observed in samples from all three members. Laumontite is the most common type, but analcite, and possibly stilbite also occur. The only sample from Member C found to contain zeolite was 5-1, which contains a significant amount (13%). Zeolite is more widely distributed in Lashly D. Quartz overgrowths were observed in nearly all samples, but is more extensive in Lashly D. Authigenic quartz cement was also observed in thin sections from higher in the sequence. With the exception of compaction of detrital mica flakes, these alteration characteristics probably result from either syn- or post-Ferrar hydrothermal activity (Ballance and Watters, 2002).

6.5 Beacon – Mawson contact relationships

The contact between the Mawson Formation and the older Beacon Supergroup is exposed at two of the localities visited during this field season at Coombs Hills. At locality 4A, a steeply dipping, intrusive contact was observed between ash-bearing sandstones and tuff breccia. This contact occurs at the top of section 4A, 250+ meters above the base of Lashly D. The second place the contact was observed was locality 6. The relationship here is complex because of a contact zone of tilted strata, blocks of sedimentary rocks, and sandstone dikes. Many of the sandstones adjacent to the contact have very poor stratification, and contain a large abundance of pustular bodies (crystallization of zeolite) thought to be a result of phreatic activity. Complex relationships make it difficult to interpret this contact with certainty.

At locality 4, 150 meters of Jurassic Mawson Formation occur above the thickest known sequence of Lashly D. White and McClintock (2001) interpret the Mawson Formation as representative of a phreatocauldron below paleo-land surface. Therefore, caldera walls provided the confining topography in which tuff breccia accumulated such a massive thickness. Observations at locality 4 require that either 150 meters of section, possibly equivalent to the Hanson Formation, are missing, or that above this the Mawson Formation occurs as an extra-vent facies.

CHAPTER 7:

CONCLUSIONS

The presence of the Lashly Formation at Coombs Hills has been confirmed, and individual members have been identified. The upper three members, Members B, C, and D, crop out and have been mapped in detail in an area east of Mt. Brooke. Lashly D was found to have a greater thickness (250.8 meters) than previously recorded elsewhere in south Victoria Land. The upper 50 meters of the Lashly Formation contains an abundance of silicic glass shards, indicating contemporaneous volcanism at the time of emplacement. Following further investigation it may be appropriate to designate this interval as a new unit equivalent to the Hanson Formation of the central Transantarctic Mountains. These strata have been disturbed by phreatic activity, which is most likely related to emplacement of the Mawson Formation.

The contact relationship between the Mawson Formation and upper Lashly D strata is intrusive. This contact relationship, along with the great thickness (>350 meters) of tuff breccia suggests the interpretation set forth by White and McClintock (2001) may need to be revised. The lower part of the Mawson Formation was emplaced as an intrusive body as previously suggested. The upper part, which consists of at least a 150 meter thickness of tuff breccia above the stratigraphically highest Lashly beds, requires either some additional type of confining topography above the Lashly beds, or that it accumulated stratigraphically as an extra-vent deposit.

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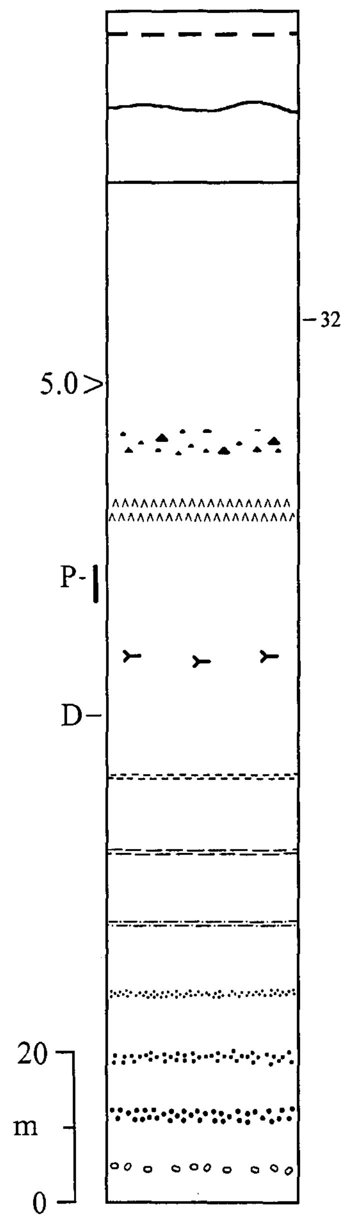
APPENDIX A

STRATIGRAPHIC COLUMNS

EXPLANATION:



Intrusive contact

Erosional contact

Stratigraphic contact

Snow or scree covered interval

Sample number

Sill or dike thickness

Volcanic tuff breccia

Silicic tuff

Pustular beds

Log or stem fragments

Dicroidium flora

Carbonaceous mudstone

Light grey mudstone

Siltstone

Fine sandstone

Medium sandstone

Coarse sandstone

Pebbly sandstone

Vertical Scale: 1 cm = 10 m

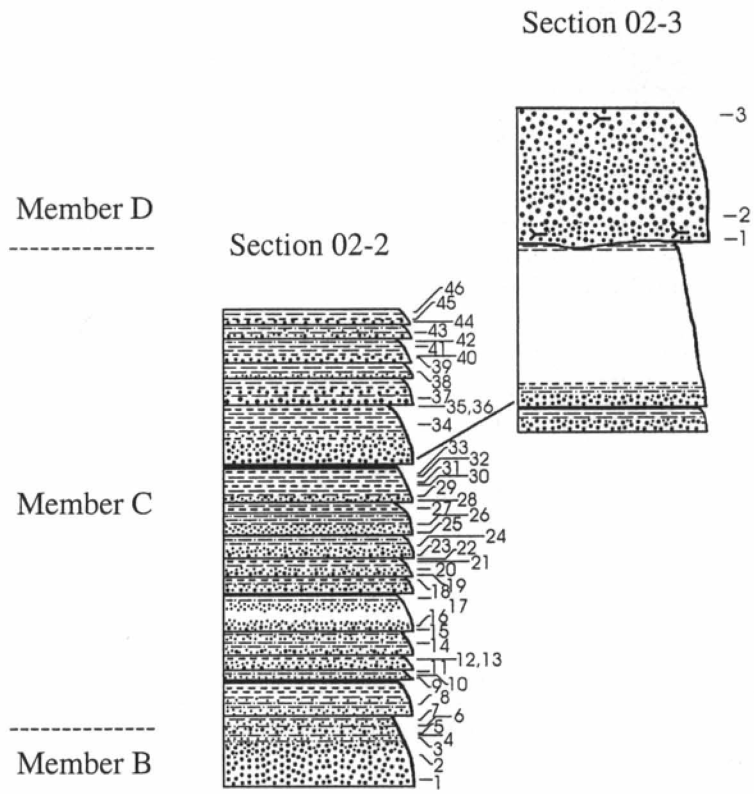


Figure A.1 Sections 02-2 and 02-3. Includes the upper part Lashly B, Lashly C, and the lower part of Lashly D.

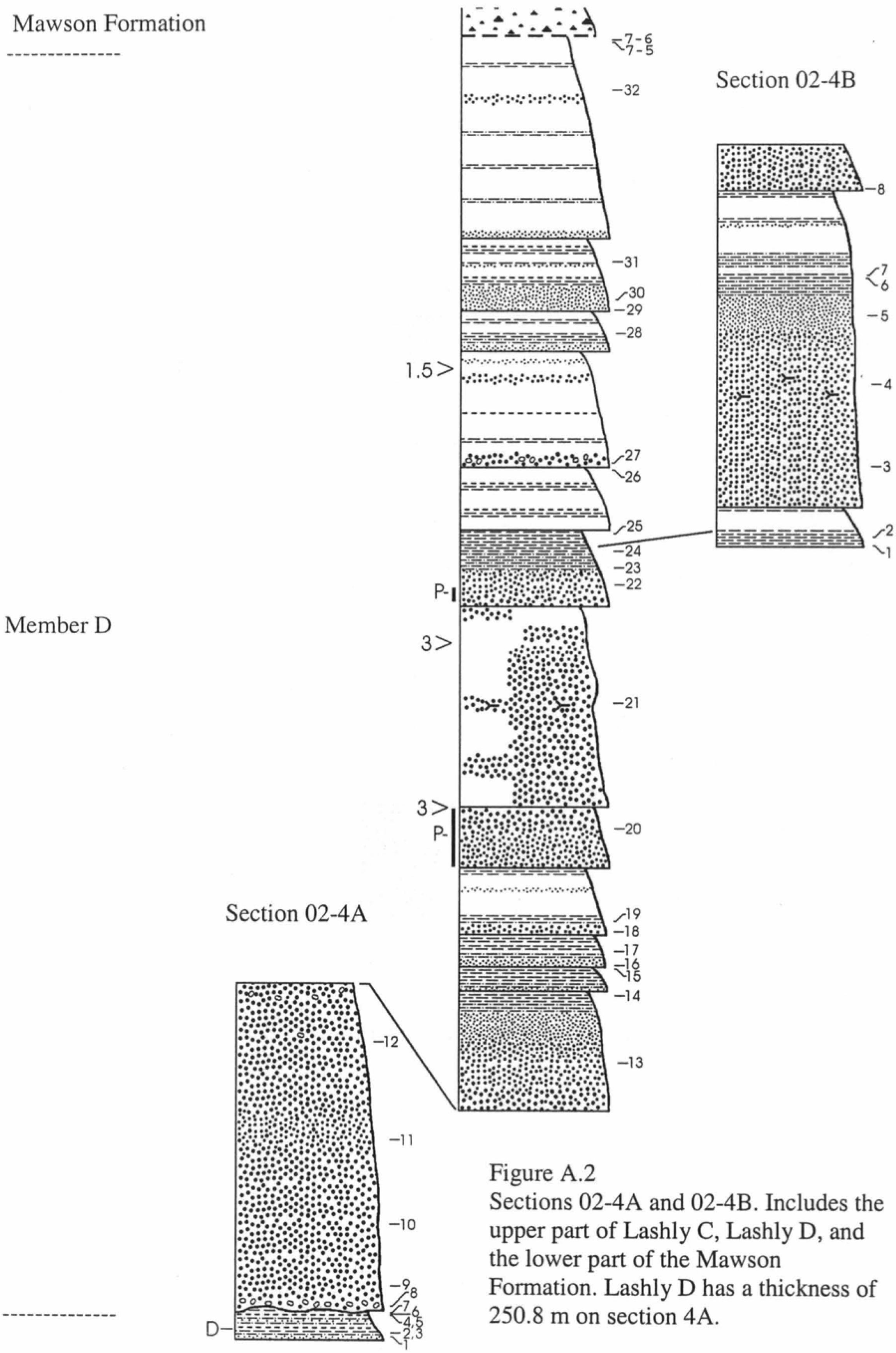


Figure A.2
Sections 02-4A and 02-4B. Includes the upper part of Lashly C, Lashly D, and the lower part of the Mawson Formation. Lashly D has a thickness of 250.8 m on section 4A.

Section 02-5

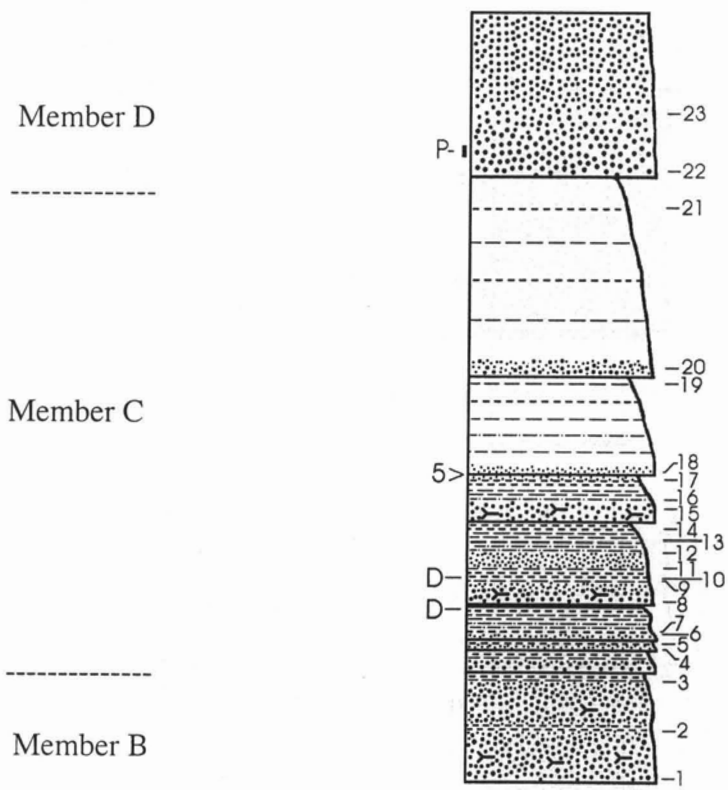


Figure A.3 Section 02-5. Includes the upper part of Lashly B, Lashly C, and the lower part of Lashly D.

Section 02-6

Mawson Formation

Member D

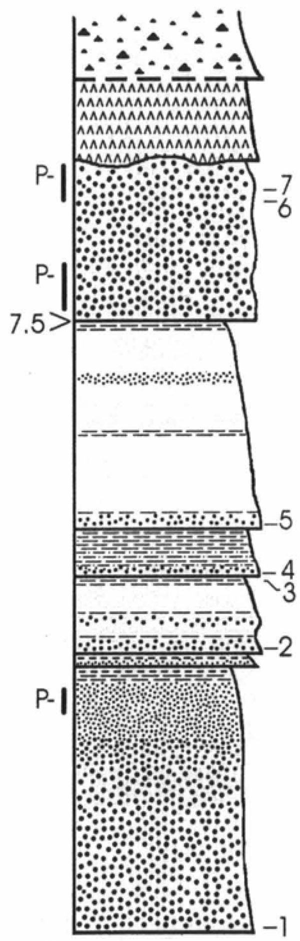


Figure A.4 Section 02-6. Includes Lashly D, and the lower part of the Mawson Formation.

Section 02-8

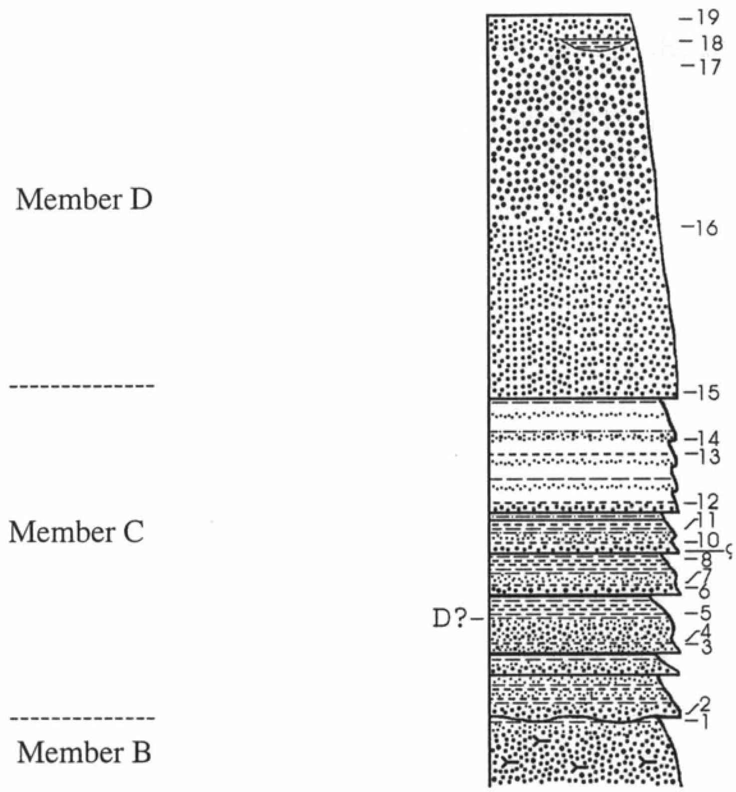


Figure A.5 Section 02-8. Includes the upper part of Lashly B, Lashly C, and the lower part of Lashly D.

APPENDIX B

STRATIGRAPHIC SECTION

DESCRIPTIONS

Section 02-2 - COOMBS HILLS.

Section measured from the western end of the small sandstone platform lying east of Mt. Brooke, north up a slope. Measured with staff and level by DHE, TJC, CBG 11/03.
Position of base 76° 49' S; 160° 03.344' E.   Altimeter elevation 1700 m.

Unit		Thickness (m) Unit	Section
	Section runs out where two phreatic bodies converge.		
	LASHLY FORMATION (63+ m)		
17	Sandstone, grey with greenish tint, fine grained, carbonaceous. Grey siltstone at 30 cm, varying amounts of carbonaceous material, overlain by alternating fine sandstone, flaky l. grey siltstone, and black shaly mudstone.	2.4	63.3

Sample			
Sample	02-2-46	1.5 m	Light grey mudstone.
	02-2-45	0.55 m	Medium grey mudstone.
	02-2-44	0.6 m	Medium grey siltstone.

- gradational contact -

Unit		Unit	Section
16	Sandstone, grey w/ iron staining, medium-coarse, contains spherical, ferruginous concretions. Fines upwards into alternating beds of fine sandstone, light grey siltstone, and medium grey carbonaceous siltstone.	1.9	60.9

Sample	02-2-43	0.6 m	Light grey mudstone.

- gradational contact -

Unit		Unit	Section
15	Sandstone, medium, base is burrowed, 3-4 mm ferruginous concretions. Grades into fine sandstone with ripple cross laminations. Coaly shale from 75-85 cm, overlain by alternating carbonaceous siltstone, mudstone, and crosscut by numerous coarse sandstone dikes about 1 cm thick.	3.3	59.0

Sample	02-2-42	2.5 m	Grey laminated sandstone.
	02-2-41	2.0 m	Mudstone.
	02-2-40	0.55 m	Medium sandstone.
	02-2-39	0.5 m	Sandstone.

Unit		Unit	Section
14	Sandstone, greenish grey, fine grained w/ poor ripple cross laminations. Fines up into light-medium grey, carbonaceous, laminated mudstone.	1.8	55.7

Sample	02-2-38	0.6 m	Laminated mudstone.

Unit		Unit	Section
13	Interbedded fine sandstones and mudstones, both slightly carbonaceous. Black, platy, carbonaceous shale at 3.0 m, grading into less carbonaceous mudstone. Occasional wavy beds of very coarse sandstone up to 2 cm thick, micaceous with quartz, plagioclase, orange lithic fragments, and mud flakes.	3.5	53.9

Sample	02-2-37	1.0 m	Coarse sandstone.

		02-2-36	0.3 m	Mudstone.	
		02-2-35	0.35 m	Mudstone.	

Note: Transferred west laterally along thin sandstone bluff approximately 25 m.

12	Sandstone, medium, red lithics, micaceous, abundant ripple cross laminations, basal 10 cm mixed up with coal and sandstone. Lens of greenish brown sandstone from 1.2 - 1.4 m, massive to very flaky. Black to dark grey carbonaceous mudstone from 3.1 - 3.3 m. Sandstone same as below 1.2 m, slightly finer, abundant ferruginous concretions, greenish to grey. Shaly mudstone at 7.7 m, greenish to black with carbonaceous material, thinly bedded.	7.8	50.4

Sample	02-2-34	5.1 m	Grey mudstone.

- slightly erosional contact -

11	Sandstone, light grey to yellowish, medium, thinly bedded with thin lenses of cε material. Base contains ferruginous concretions, pyrolusite. Burrows at top of bluff. Mudstone at 0.8 m, medium grey, carbonaceous, finely laminated. Grades into light grey mudstone, with thin intervals of fine sandstone. Grades into increasingly carbonaceous beds. Coal at 4.0 m, 80 cm thick.	4.8	42.6

Sample	02-2-33	3.7 m	Grey mudstone.
	02-2-32	3.4 m	Grey mudstone.
	02-2-31	2.4 m	Light grey mudstone.
	02-2-30	2.3 m	Grey mudstone.
	02-2-29	0.9 m	Grey mudstone.
	02-2-28	0.25 m	Micaceous sandstone.

- gradational contact -

10	Sandstone like base of Unit 9, grading into micaceous, finer, well developed ripple cross laminations. Grey carbonaceous mudstone at 1 m. Grades into fine sandstone, poor ripple cross laminations. Fines into carbonaceous siltstone, black to grey. Thin Coal bed at 3.4 m, 5 cm thick. Grades into carbonaceous mudstone, grey, thinly laminated, lightening upward.	4.4	37.8

Sample	02-2-27	3.6 m	Grey mudstone.
	02-2-26	1.2 m	Grey mudstone.
	02-2-25	0.1 m	Sandstone.

- slightly erosional contact -

9	Sandstone, light grey to yellowish, fine to medium, basal 30 cm has abundant black, ferruginous concretions. Fines into more carbonaceous fine sandstone and siltstone. Coal at 3.3 m, 10 cm thick.	3.4	33.4

Sample	02-2-24	1.5 m	Very fine sandstone.
	02-2-23	0.1 m	Medium to fine sandstone with black concretions.

- gradational contact -

8 Sandstone, yellowish to greenish grey, medium. Fines into laminated mudstone medium grey. Grades into micaceous sandstone, fine, well developed ripple cross laminations. 2.4 30.0

Sample	02-2-21	2.1 m	Medium grey, fine siltstone.
	02-2-20	1.0 m	Grey, finely laminated siltstone.
	02-2-19	0.1 m	Medium sandstone.

- gradational contact -

7 Sandstone, orange to grey, iron stained, medium, small trough cross beds, horizon of 5 - 10 mm black concretions, burrows between cross beds. Fines into slope forming sandstone, fine, carbonaceous. Fines into medium grey shale, then coaly mudstone, finely laminated. 2.3 27.6

Sample	02-2-18	2.0 m	Finely laminated, grey siltstone.

- sharp contact -

6 Sandstone, medium to fine, trough cross beds up to 15 cm, iron staining. Fines into fine sandstone, grey, micaceous, some ripple cross laminations. Scree slope from 2.1 - 4 m. Fine sandstone ridge, with large vertical burrows, up to 30 cm long. Coal at 4.3 m, 20 cm thick. 4.5 25.3

Sample	02-2-17	4.2 m	Grey, fine sandstone.
	02-2-16	0.8 m	Fine sandstone.
	02-2-15	0.1 m	Medium sandstone.

- gradational contact -

5 Sandstone, yellowish-orange to grey, medium to fine, micaceous, dark grey, carbonaceous stringers abundant. Fines into sandstone, fine, grey, micaceous, and siltstone. Few ferruginous concretions near top of unit. 3.3 20.8

Sample	02-2-14	1.7 m	Grey siltstone.

- gradational contact -

4 Sandstone, reddish brown, medium, basal 20 cm strongly burrowed. Fines into slope forming sandstone, grey, fine, micaceous. Black mudstone at 1.8 m, thinly bedded, plant fragments common (Dicroidium?). Grades into fine siltstone, grey. 2.0 17.5

Sample	02-2-13	1.95 m	Fine siltstone.
	02-2-12	1.9 m	Mudstone with plant fragments.

- gradational contact -

3 Sandstone, orange to grey, medium, quartzose, ripple cross laminations well developed. Fines into siltstone, grey, micaceous, slightly carbonaceous. 1.5 15.5

Sample	02-2-11	1.4 m	Fine, carbonaceous siltstone.		
	02-2-10	0.55 m	Fine sandstone.		
	02-2-9	0.2 m	Medium sandstone.		

- sharp contact -

2 Sandstone, grey, fine, well developed ripple cross laminations. Becomes increasingly carbonaceous and finer grained, few stems fragments. Coaly mudstones at 1.3 m, interbedded with grey, shaly mudstones. Coal at 3.7 m, 60 cm thick. 4.3 14.0

Sample	02-2-8	1.1 m	Grey siltstone.

- gradational contact -

1 Sandstone, orangish-red to yellowish orange, medium, quartzose, large, sweeping trough cross beds, few small ferruginous concretions, exposed as a large platform forming sandstone. Ripple cross laminations abundant on surfaces. Fines into micaceous sandstone at 1.6 m. Dolerite sill from 2.6 - 3.2 m. Ferruginous concretions more abundant at 4.0 m, up to 1 cm in diameter, trough cross beds up to 50 cm thick. Alternating fine sandstones, grey siltstones, and carbonaceous siltstones from 6.2 - 9.7 m, oscillatory ripples present. Finer carbonaceous beds become dominant over fine sandstones in top 3 meters. Small burrows occasional beneath fine sandstone. 9.7 9.7

Sample	02-2-7	8.8 m	
	02-2-6	7.6 m	
	02-2-5	6.7 m	
	02-2-4	6.5 m	
	02-2-3	6.3 m	
	02-2-2	4.0 m	Fine, micaceous sandstone.
	02-2-1	2.0 m	Medium, quartzose sandstone.

Platform sandstone.

<u>LASHLY FORMATION (63+ m)</u>

Section 02-3 - COOMBS HILLS

Section measured approximately 100 meters west of the top of section 02-2, beginning on top of the 80 cm thick coal bed that occurs 42.6 m above the base of section 02-2. Measured with staff and level by CBG, TJC, 11/03.

Unit		Thickness (m) Unit	Section
	Section runs out at base of Tertiary/Quaternary tillite.		
	LASHLY FORMATION (45+ m)		
3	Sandstone, grey to brown, medium to coarse, quartzose, iron staining, basal 0.9 m contains large, grey mud and siltstone clasts up to 15 cm long, carbonaceous material, round and losenge shaped concretionary bodies up to 3 cm long, coalified wood fragments in lower 1.5 m up to 25 cm long, faintly crossbedded. Becomes more strongly crossbedded, coarser, and iron stained at 1.2 m. Trough crossbeds well developed at 6.0 m. Thin, carbonaceous stringers become evident at 7.5 m, and concretions very abundant. Greenish layer, 4 cm thick at 8.5 m. Small mud clasts occur at 11.0 m at the base of a channel sandstone, coarse, small coalified wood fragments up to 4 cm, concretions.	16.9	44.9

Sample	02-3-3	16.5 m	Coarse sandstone.
	02-3-2	3.0 m	Coarse sandstone with concretionary bodies.
	02-3-1	0.2 m	Medium to coarse sandstone.

- erosional contact -

2	Sandstone, grey, medium to fine. Fines up into grey siltstone. Poorly exposed, snow and scree covered from 7.5 to 24.5 m. Mudstone, med grey, in upper most 50 cm, interbedded with grey siltstone.	25.0	28.0

- sharp contact -

1	Sandstone, olive greenish to grey, medium. Fines up into grey siltstone and slightly carbonaceous mudstone, becoming increasingly carbonaceous. Coal at 2.9 m, 10 cm thick.	3.0	3.0

0.8 m thick coal bed.

LASHLY FORMATION (45+ m)

Section 02-4A - COOMBS HILLS

Section began on east end of the east - west trending ridge lying in between the two large glaciers southeast of Mt. Brooke, at first exposure of bluish grey carbonaceous mudstone. Measured with staff and level by CBG, DHE, TJC 11/03.
Position at base 76° 49.28' S; 160° 00.8' E. Altimeter elevation 1920 m.

Unit		Thickness (m) Unit	Section
	Section capped by Mawson Formation.		
	LASHLY FORMATION (250+ m)		
20	Sandstone ledge similar to unit 14, 0.7 m thick. Fines up into siltstones and mudstones, but very poor exposure. Scree covered. Sandstone, 40 cm thick at 25.3 m, medium to fine, black lithic components abundant. Scree covered.	34.5	250.8
	Sample 02-4-32 25.5 m Medium sandstone.		
	- gradational contact -		
19	Sandstone, whitish grey, very fine, quartzose, laterally discontinuous. Fines up into alternating beds of very thin sandstone beds, light grey siltstones, and light to medium grey mudstones at 4.4 m. Poorly exposed.	12.4	216.3
	Sample 02-4-31 7.8 m Medium grey mudstone. 02-4-30 1.8 m Very fine sandstone. 02-4-29 0.1 m Light grey laminated siltstone.		
	- covered contact -		
18	Sandstone, grey, fine, 0.7 m thick. Fines up into greenish grey mudstone, interbedded light grey mudstone and siltstone.	6.5	203.7
	Sample 02-4-28 2.7 m Greenish grey mudstone.		
	- covered contact -		
17	Dolerite dike, 1.6 m thick. Overlain by poorly exposed sandstone, medium, scree covered.	4.5	197.2
16	Sandstone, yellowish orange, iron staining, coarse to pebbly, quartzose, poorly preserved trough cross bedding, some small carbonaceous debris, ledge about 1.2 m thick. Fines up into poor exposure of fine sandstone with ripple cross laminations, siltstone, greenish grey to light grey mudstones. Poorly exposed sandstone ledge at 14.7 m, coarse, 30 cm thick.	16.9	192.7
	Sample 02-4-27 0.5 m Coarse sandstone.		
	- covered contact -		
15	Poor exposure. Minimal exposure of dark grey, carbonaceous mudstone, light grey mudstone, and grey papery mudstone.	11.2	175.8

	Sample 02-4-26 10.0 m Light grey mudstone.			
14	Dolerite sill. Solitary pod of bluff sandstone, medium to coarse, quartzose, on sill.		164.6
	Sample 02-4-25 On sill Medium to coarse sandstone.		
	Note: Sill thickness excluded from column. Measured dip of sill at 4.5 degrees west; visually estimated this to be same as that of the surrounding strata. Traversed along sill southwesterly down dip approximately 400 m, and resumed measuring up additional section.		
13	Sandstone, yellowish orange to grey, medium to coarse, faint ripple cross laminations, small pustular concretions up to 4 mm. Siltstone at 6.1 m, greenish grey, thinly bedded, carbonaceous. Mudstone at 9.1 m, white to very light grey, more carbonaceous mudstone occasional between white mudstone ledges.	12.0	164.6
	Sample 02-4-24 9.5 m Light grey mudstone. 02-4-23 6.4 m Greenish grey siltstone. 02-4-22 3.7 m Medium sandstone.		
12	Dolerite intruded sandstone, like unit 10.	7.5	152.6
11	Dolerite intrusion.	3.0	145.1
10	Sandstone, yellowish orange, coarse, poor stratification with occasional remnant crossbeds, some greenish concretions up to 5 mm, carbonaceous, fossil and coalified wood fragments up to 25 cm long. Mudstone, light grey, at 22.7 m. Grades into coarse to pebbly sandstone, like basal sandstone. From 22.7 to 27 m appears to be extremely disturbed by intrusive body. Entire unit somewhat disturbed by pods of dolerite which our discontinuous, but abundant.	27.0	142.1
	Sample 02-4-21 18.3 m Coarse sandstone.		
9	Dolerite intrusion.	3.2	115.1
8	Sandstone, yellowish to grey, slight greenish tint, medium to coarse, poorly developed ripple cross laminations, abundant pustular concretions up to 5 mm. Grades into coarse sandstone.	10.5	111.9
	Sample 02-4-20 6.7 m Coarse sandstone.		
	- covered contact -		
7	Sandstone, yellowish orange with slight grey tint, medium, carbonaceous stringers, base intermixed with grey mudstone clasts up to 10 cm, ripple cross laminations, some woody debris, ledge forming up to 1.2 m. Sandstone dike crosscutting at 1.2 m, 60 cm thick, clasts of mudstone, shale, and coaly debris common. Silty mudstone at 1.8 m, light grey, very hard, occasional interbedded thin sandstone, fine. Poorly exposed.	11.3	101.4

	Sample 02-4-19 2.0 m Light grey, silty mudstone.				
	02-4-18 0.2 m Medium sandstone.				
	- contact slightly erosional -				
6	Sandstone, yellowish pink to light grey, fine to very fine, alternation of pinkish and grey laminae in first 40 cm. Fines up into light grey, slightly carbonaceous mudstone, with light blue tint near top.			5.6	90.1
	Sample 02-4-17 2.5 m Light grey mudstone.				
	02-4-16 0.35 m Fine pinkish sandstone.				
	- gradational contact -				
5	Sandstone, fine to medium, yellowish orange with slight green tint, micaceous, little carbonaceous material, ripple cross laminations. Fines up into mudstone, medium to light grey, with slight pinkish alteration.			4.1	84.4
	Sample 02-4-15 4.0 m Grey mudstone.				
	- gradational contact -				
4	Sandstone, orangish yellow, iron stained, coarse to pebbly, pebbles up to 7 cm but mostly less than 2, quartzose, trough cross bed sets up to 30 cm thick, bluff former. Fines up into medium sandstone, poorly exposed scree slope from 10.6 m up to 14.4 m. Medium grey mudstone, slightly laminated exposed in uppermost 50 cm.			14.9	80.3
	Sample 02-4-14 14.7 m Medium grey mudstone.				
	02-4-13 3.4 m Coarse sandstone.				
	- gradational contact -				
3	Sandstone, like unit 2.			4.8	65.4
	Note: Traversed on top of sandstone bluffs south/southwest around the hillside to sandstone platform.				
2	Sandstone, yellowish orange, very coarse to pebbly with pebbles up to 2 cm, quartzose, basal 75 cm contains mud clasts, coaly fragments up to 25 cm long, occasional black concretions, garnet bearing. Fines up into coarse sandstone after 75 cm, with pebbly layers intermittent, faint trough cross bedding, bluff forming. Trough cross bed sets well developed after 4.0 m, up to 1 m thick. Sandstone appears jumbled or disturbed in some areas, seen by disrupted cross bedding. Occasional lenses with mud clasts and coaly debris. Scree covered in some areas, but fairly well exposed.			56.0	60.6
	Sample 02-4-12 10.0 m Coarse sandstone, with mud clasts.				
	02-4-11 34.0 m Baked sandstone.				
	02-4-10 51.0 m Coarse sandstone.				
	02-4-9 4.0 m Coarse sandstone.				
	02-4-8 0.5 m Coarse, pebbly sandstone.				

- erosional contact -

1	Alternating fine sandstone, light grey, micaceous, and carbonaceous mudstones and siltstones, blue tint, with plant fragments. Poor ripple cross laminations. Finer grained, carbonaceous beds much more common. Horizon with Dicroidium flora at 1.3 m. Resistant sandstone ledge at 1.9 m, light grey with greenish tint, 30 cm thick. Fines into silty mudstone and shale, medium to dark grey, carbonaceous. Resistant sandstone ledge at 3.0 m, 8 cm thick. Fines up into carbonaceous shale, and mudstone, very hard, with bluish tint.	4.6	4.6

Sample	02-4-7	4.35 m	Silty mudstone.
	02-4-6	4.3 m	Silty, hard, bluish mudstone.
	02-4-5	4.4 m	Hard, bluish mudstone.
	02-4-4	4.5 m	Light grey mudstone.
	02-4-3	1.3 m	Medium grey mudstone with Dicroidium flora.
	02-4-2	1.3 m	Sandy, micaceous siltstone.
	02-4-1	0.4 m	Medium sandstone.

LASHLY FORMATION (250+ m)

Covered by dolerite scree.

Section 02-4B - COOMBS HILLS

Section measured on the south side of an east - west trending ridge in between two large glaciers southeast of Mt. Brooke, beginning at hard white mudstone horizon believed to be the same stratigraphic horizon that occurs at the top of unit 10, section 02-4. Measured with staff and level by CBG, TJC 11/03.
Position at base 76º 49.548' S; 159º 59.891' E.

Unit		Thickness (m) Unit	Section
	Dolerite dike capping summit.		
	LASHLY FORMATION (68+ m)		
5	Sandstone, orange with iron staining, medium to coarse, quartzose, thin carbonaceous stringers common, few mud clasts near base up to 10 cm, bluff forming. Fines up into medium to fine grained sandstone, slope forming.	7.8	67.8

Sample	02-4B-9	0.1 m	Medium sandstone with mud clasts.

- gradational contact -

4	Sandstone bluff, light grey, very fine to fine, slight iron staining, massive, 3 m thick. Poorly exposed from 3.0 to 7.0 m. Ledge of medium to fine sandstone at 7.0 m, light grey. Fines into light grey, muddy shale from 7.5 to 8.0. Grades into a sandstone ledge like the one at 7.0 m, with thin carbonaceous stringers. Snow and scree covered from 9.0 to 14.0 m. Mudstone, light to medium grey in upper 50 cm of unit.	14.5	60.0

- covered contact -

3	Sandstone, yellowish orange to light orange, medium to coarse, quartzose, thin carbonaceous stringers, fossil log fragments from 0.5 to 3.0 m, extremely quartzose lenses up to 75 cm in length, remnant crossbedding sets up to 50 cm thick bluff is 9.0 m thick. Fines up into fine to very fine sandstone, light grey, and grey shaly mudstone, carbonaceous with plant fragments. Poorly exposed slope from 16.3 to 17.0 m.	17.0	45.5

Sample	02-4B-8	16.7 m	Grey mudstone.
	02-4B-7	16.5 m	Dark grey mudstone.
	02-4B-6	9.3 m	Light grey shale.

- gradational contact -

2	Sandstone, light olive green to grey color, slight iron staining, medium to coarse, uncommon pustular concretions up to 4 mm, poor trough cross bedding sets up to 30 cm thick, slope forming. Similar lithology up section, with pustules up to 1 cm, coarser grained, more yellowish to grey with slight greenish tint. Becomes more carbonaceous with woody debris from 19.5 to 22 m, quartzose, yellowish orange, trough cross bedding sets up less than 10 cm.	22.5	28.5

Sample	02-4B-5	20.4 m	Coarse sandstone.

	02-4B-4	6.5 m	Medium to coarse sandstone.

- covered contact -

1 Mudstone, light grey to white, very hard, massive, blocky or poddy weathering. Grey shaly mudstone from 0.4 to 0.7 m. Same resistant, white mudstone from 0.7 to 0.9 m. This sequence is repeated once more, with a third white mudstone ledge occurring from 2.0 to 2.2 m.Followed by a poorly exposed slope, composed primarily of fine grained, grey, carbonaceous beds. 6.0 6.0

Sample	02-4B-3	1.8 m	Grey, shaly mudstone.
	02-4B-2	0.6 m	Grey shaly mudstone.
	02-4B-1	0.3 m	Hard, white mudstone.

<u>LASHLY FORMATION (68+ m)</u>

Poorly exposed scree slope.

Section 02-5 - COOMBS HILLS

Section measured beginning in the southwest corner of the large sandstone platform east of Mt. Brooke, walking west up the slope. Measured with staff and level by DHE, CBG, TJC 11/03. Position at base 76^{0} 48.482' S; 160^{0} 01.360' E. Altimeter elevation 1870 m.

Unit		Thickness (m) Unit	Section
	Dolerite sill capping summit.		
	LASHLY FORMATION (107+ m)		
11	Sandstone, yellowish orange to light grey, coarse to pebbly near base, quartzose, trough cross bedding sets from 0.4 to 1 m, some yellowish orange pustules, bluff forming. Fines to a medium sandstone at 5 m.	23	106.2
	Sample 02-5-23 7.0 m Medium sandstone. 02-5-22 1.0 m Coarse sandstone.		
	- covered contact -		
10	Poorly exposed, frost heaved surface. Blocks largely composed of fine, grey, carbonaceous mudstone and siltstone.	22.8	83.2
	Sample 02-5-21 22.3 m Light grey mudstone.		
	- covered contact -		
9	Sandstone ledge, light grey, slight iron staining, fine to medium.	1.2	60.4
	Sample 02-5-20 0.7 m Fine to medium sandstone.		
	- gradational contact -		
8	Frost heaved surface, largely an alternating sequence of fine to medium sandstone, carbonaceous siltstone, flaky light grey to greenish shale, and coaly shale. Few beds are observable undisturbed.	14.0	59.2
	Sample 02-5-19 13.0 m Greenish grey mudstone. 02-5-18 0.5 m Fine sandstone.		
7	Dolerite intrusion.	4.8	45.2
6	Sandstone, yellowish grey with slight greenish tint, medium, trough cross bedding sets from 40 to 50 cm, coaly debris, log fragments up to 40 cm long, iron concretions in lower 1 m, bluff is 3.5 m thick.	6.2	40.4
	Note: Tranfer laterally 30 m west along bluff sandstone.		
	Fines up into grey siltstone and mudstone. Black, coaly shales from 5.0 to 6.0 m. Grades into poorly exposed, thin ledge of fine sandstone, then into a thin lense of greenish grey mudstone.		

Sample	02-5-17	6.0 m	Fine, light grey sandstone.
	02-5-16	3.2 m	Light grey mudstone.
	02-5-15	1.7 m	Medium sandstone.

- gradational contact -

5	Sandstone, yellowish grey with orange weathering, medium, micaceous, well developed cross bedding sets up to 20 cm thick, 0.8 m thick ledge.Fines up into alternating sequence of carbonaceous shale, mudstone, coaly shale, and thin siltstone and fine sandstone. Layer of dark grey mudstone with abundant plant fragments, especially Dicroidium flora, at 2.7 m. Grades into a thin, laminated, fine, grey sandstone ledge at 6.3 m, which quickly fines into a grey siltstone, then into finer, carbonaceous beds.	11.0	34.2

Sample	02-5-14	10.0 m	Grey shale.
	02-5-13	8.3 m	Light grey siltstone.
	02-5-12	6.6 m	Fine, laminated sandstone.
	02-5-11	4.7 m	Light grey mudstone.
	02-5-10	2.8 m	Dark grey mudstone with plant megafossils.
	02-5-9	2.8 m	Dark grey mudstone with Dicroidium flora.
	02-5-8	0.5 m	Medium sandstone.

4	Sandstone, grey, fine, micaceous, channelled. Grades into finer beds bearing Dicroidium flora, then back into a thin ledge of fine sanndstone at 2.5 m. Fines up into finer carbonaceous beds, black shale, and shaly coal.	4.6	23.2

Sample	02-5-7	1.9 m	Grey mudstone with plant fragments.
	02-5-6	1.5 m	Dark grey mudstone.

3	Sandstone, light grey, fine to medium, carbonaceous, micaceous, forms a ledge and small platform on which abundant fossil wood float is found. Black, carbonaceous shale with plant fragments at 0.8 m.	1.3	18.6

Sample	02-5-5	0.9 m	Black shaly mudstone with plant fragments.
	02-5-4	0.2 m	Fine, carbonaceous sandstone.

2	Sandstone, yellowish grey, fine to medium, micaceous, crossbedding sets less than 4 cm, ledge forming, 1.2 m thick. Fines up into light grey siltstone, then carbonaceous, black, flaky shle and mudstone with few plant fragments.	2.7	17.3

1	Sandstone, orange to yellowish brown, medium, quartz rich, trough bedding sets from 10 to 30 cm, pustular bodies up to 4 mm, log fragments up to 80 cm. Thin layer at 7.1 m bearing coaly material in a medium sand matrix, about 30 cm thick. Fines into carbonaceous siltstone at 14.2 m, light to dark grey, with some shaly interbeds.	14.6	14.6

Sample	02-5-3	14.3 m	Carbonaceous siltstone.
	02-5-2	7.3 m	Carbonaceous sandstone.
	02-5-1	1.0 m	Medium sandstone.

Large sandstone platform.

LASHLY FORMATION (107+ m)

Section 02-6 - COOMBS HILLS

Section measured on northwest edge of large platform east of Mt. Brooke, 550 m north of section 02-8, from base of slope forming sandstone. Measured with staff and level by CBG, TJC 11/03. Position at base 76° 48.389' S; 159° 58.993' E. Altimeter elevation 1920 m.

Unit		Thickness (m) Unit	Section
	Mawson Formation overlying section.		
	Tuff, white, very hard.	11.1	120.0
	LASHLY FORMATION (109+ m)		
6	Sandstone, orange to yellow, coarse, very pustular, disturbed crossbedding, numerous small, discontinuous pods of dolerite jumbling bedding. Fossil log fragments, little carbonaceous debris at 16.5 m, light grey to yellowish sandstone, medium to coarse, some iron staining.	21	108.9
	Sample 02-6-7 16.5 m Disturbed medium sandstone.		
	02-6-6 15.7 m Pustular sandstone.		
	- jumbled contact -		
5	Dolerite dike.	7.5	87.9
4	Sandstone ledge, light grey to yellowish, 20 cm thick, ripple cross laminations. Followed by a poorly exposed scree slope. Finer, carbonaceous beds occur, but outcrop to poor to describe.	27.0	80.4
	Sample 02-6-5 0.1 m Fine to medium sandstone.		
3	Sandstone ledge, light grey to yellowish, medium to fine, 40 cm thick. Poorly exposed after ledge, but carbonaceous siltstones and mudstones observable.	6.4	53.4
	Sample 02-6-4 0.5 m Grey shaly mudstone.		
2	Sandstone, greyish brown, medium to fine, ripple cross laminations. Alternating interval of siltstone, carbonaceous mudstone, and thin sandstone beds occur on a poorly exposed slope, few small plant fragments.	10.1	47.0
	Sample 02-6-3 10.0 m Dark grey mudstone.		
	02-6-2 0.1 m Medium to fine sandstone.		
	- covered contact -		
1	Sandstone, yellowish orange, medium grained, trough crossbedding sets 20-40 cm, small pustular bodies common, less than 5 mm. Thin, grey silty bed at 30 m. Horizon with ferruginous concretions at 35 m, resistant, overlain by interbedded sandstone and carbonaceous muddy siltstone. Fines up into carbonaceous siltstones, shale, and flaky mudstone with poor exposure.	36.9	36.9

Sample 02-6-1 0.5 m Medium sandstone.

Poorly exposed scree covered slope, grey color with greenish tint.

Large sandstone platform.

<u>LASHLY FORMATION (109+ m)</u>

Section 02-8 - COOMBS HILLS

Section measured in the western corner of a large sandstone platform east of Mt. Brooke, from the platform walking north-northwest up a slope. Measured with staff and level by DHE, CBG, TJC 11/03. Position at base 76° 48.539' S; 159° 59.608' E. Altimeter elevation 1910 m.

Unit		Thickness (m) Unit	Section
	Dolerite scree slope up to Mawson Formation.		
	LASHLY FORMATION (92+ m)		
10	Sandstone, greyish orange, medium, occasional small pustular bodies, trough crossbed sets from 0.3 to 1 m, steep slopeforming. Coarsens up into coarse sandstone, quartzose, carbonaceous stringers, woody fragments at 25 m. Very coarse sandstone at 45 m, with pebbles up to 5 mm. Fines to medium to coarse sandstone, trough crossbed sets up to 30 cm. Thin lense of carbonaceous mudstone at 47.0 m.	50.2	91.7

Sample	02-8-19	50.0	Medium sandstone.
	02-8-18	47.0	Grey mudstone.
	02-8-17	44.9	Coarse sandstone.
	02-8-16	25.0	Medium to coarse sandstone.
	02-8-15	1.0 m	Medium sandstone.

- sharp contact -

9	Interval snow and scree covered, alternating sandstone and finer beds like unit 6. Interval becomes more sandy up section, with multiple ledges of fine to medium, micaceous sandstone, 10 -25 cm thick, seperated by intervals of carbonaceous siltstone and mudstone. Beds begin to dip into the hill 25 degrees at 8 m. Top of this unit marked by a weak fault, with thin, upright mudstone and sandstone beds immediately adjacent to the fault.	12.6	41.5

Samples	02-8-14	8.5 m	Fine to medium sandstone.
	02-8-13	7.3 m	Grey mudstone.
	02-8-12	0.7 m	Dark grey mudstone.

Note: We offset laterally 20 m west along poorly exposed sandstone ledge.

8	Sandstone, greyish orange, fine, grades into a burrowed, iron stained sandstone at 7.0 m, ripple cross laminations.	1.3	28.9

- gradational contact -

7	Sandstone, grey to brown with a greenish tint, medium, thin carbonaceous stringers, micaceous, ledge is 1.2 m thick. Grades up into an interval of alternating thin sandstone ledges, 5 to 25 cm thick, and carbonaceous mudstones, light to dark grey. Ledges commonly burrowed, burrows up to 4 cm long. Coal at 5.1 m, 7 cm thick, grades into light grey, flaky siltstone..	6.0	27.6

Sample	02-8-11	3.7 m	Fine, laminated sandstone.

		02-8-10 1.6 m Grey mudstone.			
		02-8-9 0.1 m Medium sandstone.			

6 Sandstone, grey with greenish tint, medium to coarse, few stringers of ferruginous concretions, poor trough crossbed sets 10 to 25 cm. Fines up into fine sandstone and siltstone, slightly carbonaceous, and medium to dark grey mudstone. Coarsens into a thin sandstone ledge at 2.1 m, then fines back into medium to dark grey shaly mudstone. Grey, laminated mudstone at 5.0 m. 5.9 21.6

Sample	02-8-8	4.5 m	Grey mudstone.
	02-8-7	2.0 m	Dark grey mudstone.
	02-8-6	1.0 m	Medium sandstone.

- sharp contact -

5 Siltstone, grey, grades up into fine to medium sandstone over the next meter, bedded, ripple cross lamination truncation surfaces 2 to 4 cm apart. Fines up at 1.1 m into grey siltstone, then into medium to dark grey mudstone with plant fragments. Interbedded mudstone and siltstone at 4.5 m. Coal at 5.35 m, 5 cm thick. 5.4 15.7

Sample	02-8-5	2.5 m	Grey mudstone.

- gradational contact -

4 Sandstone, grey, medium to fine, carbonaceous with coaly stringers, strongly burrowed, few burrows up to 35 cm, but mostly less than 4 cm. Dark grey shaly mudstone at 1.6 m, with plant fragments, 30 cm thick. 2.0 10.3

Sample	02-8-4	1.8 m	Grey shale.
	02-8-3	1.5 m	Fine to medium sandstone.

- gradational contact -

3 Sandstone, greyish yellow, medium to coarse. Fines into thinly bedded, fine sandstone at 50 cm. Fines up into coaly, muddy siltstone at 1.3 m. 2.2 8.3

- gradational contact -

2 Sandstone, light grey, medium, iron staining, micaceous. Fines up into carbonaceous mudstone at 2.6 m, increasingly carbonaceous. Coarsens into fine sandstone and siltstone at 2.9 m, little carbonaceous material. Abrupt change to dark grey mudstone at 3.4 m, becoming greenish grey near 4.2 m. Grades back into laminated, carbonaceous siltstone, and fine sandstone, with thin interbeds of medium sandstone. 5.5 6.1

Sample	02-8-2	0.7 m	Medium sandstone.

- sharp contact -

1 Mudstone, medium grey. 0.6 0.6

Sample 02-8-1 0.3 m Grey mudstone.

Platform sandstone, orange, medium grained.

<u>LASHLY FORMATION (92+ m)</u>

APPENDIX C

PETROGRAPHIC DESCRIPTIONS

A brief description of common rock fragments is given here in order to avoid repetition in the thin section descriptions:

<u>Type 1 Volcanic Fragments</u>: Porphyritic and aphanitic grains with a cryptocrystalline siliceous matrix. These fragments are dusty to dirty, and greyish-brown to pale yellow in plane light. Microlites consist dominantly of quartz, and trace small opaque grains. Porphyritic grains contain sparse phenocrysts of quartz up to 0.25 mm, and often lack or contain only small amounts of phyllosilicate. Aphanitic grains commonly have varying amounts of phyllosilicate alteration, which helps distinguish them from microcrystalline or very fine-grained chert. Composition of these rock fragments is most likely dacite to rhyolite.

<u>Type 2 Volcanic Fragments</u>: Porphyritic grains with trachytic or pilotaxitic texture and a cryptocrystalline matrix. Trachytic or pilotaxitic fragments tend to be dirty, yellowish-grey to brown in plane light. Microlites of plagioclase feldspar dominate, but may include rare quartz, and opaques. Fragments usually lack any phyllosilicate alteration. Composition is intermediate to felsic.

<u>Type 3 Volcanic Fragments</u>: Other volcanic fragments not falling into either of the other types. Porphyritic to aphanitic grains with microlites of plagioclase feldspar and quartz, in a hypocrystalline or cryptocrystalline matrix. Presence of plagioclase differentiates these from Type 1. Grains appear dirty pale brown in plane light. Microlites consist of either abundant non-trachytic plagioclase feldspar with minor quartz and sparse opaque grains, or abundant quartz with only minor plagioclase, and trace opaques. Porphyritic grains have sparse phenocrysts of up to 0.16 mm, predominately of

plagioclase but also of quartz. Phyllosilicate alteration is common in these grains in varying abundances, but can be lacking. Composition is intermediate to felsic.

Glass Shards: Long, thin, very angular, glassy fragments. Shards are isotropic, and appear tan to light brown in plain light. Occasionally they exhibit a curved shape or are tricuspate, indicating the presence of vesicles during formation. Glass fragments are invariably rimmed with fine-grained mica that is colorless and has high birefringence (sericite?). Shards generally have a much greater length than width, usually from 0.08 to 0.2 mm.

Pumice: Subrounded, pale grey, fragments with abundant vesicles that have been infilled by secondary mineralization. Vesicles are setting in a network of isotropic, glassy material. Fragments have an average size of 0.15 mm.

Metamorphic Rock Fragments: The metamorphic fragments consist of low grade metasedimentary schist fragments. Schistose fragments are foliated and contain quartz and mica. Quartz can be flattened or stretched out, and aligned, or it can be rounded. Brown, white, and greenish mica are very abundant, and show poor to predominately excellent alignment within the fragments. Fragments range in size from 0.1 – 1.5 mm.

Sedimentary Rock Fragments: Yellow-brown, subangular to moderately rounded clasts of mudstone, siltstone, and very fine sandstone. Fine grained clasts contain clay-sized particles. Coarser-grained fragments contain grains up to 0.08 mm. Clast size ranges from 0.1 – 4.5 mm.

Carbonaceous Debris: Black, irregular masses that occur as globs or as long stringers. Often appear brownish and blurred in crossed polars, and lack optical properties.

Percentages given below for the individual mineral types or rock fragments are the percent of that mineral (or rock fragment) out of the total number of mineral grains (or rock fragments) for that sample. Percentages for the total amount of mineral grains, rock fragments, and matrix are given at the end of each description. Matrix constituents are extremely fine grained, and are not differentiated from cement in the following descriptions.

Sample 02-2-1

Litharenite: dusty to clear, subangular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, muscovite, chlorite, amphibole, garnet, zircon, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of phyllosilicate/clay, zeolite, and minor calcite. Quartz grains (< 0.4 mm) are monocrystalline, showing straight to undulose extinction, some with aligned and unaligned inclusions of zircon and mica, and irregular grain boundaries (38%). Biotite flakes (< 0.4 mm) are brown to pale yellow-brown with faint pleochroism, and distorted cleavage (4%). Plagioclase grains (< 0.3 mm) have albite twinning; average composition is An_{29} (2%). Potassium feldspar grains (< 0.25 mm) occur with cross hatch twinning (microcline) (1%). Muscovite flakes (< 0.4 mm) are long, thin, and colorless, with one good cleavage (< 1%). Chlorite flakes (< 0.2 mm) have pale green pleochroism, and wavy cleavage (< 1%). Amphibole grains (< 0.05) have green to pale yellow pleochroism, and 2 good cleavages (< 1%). Garnet fragments (< 0.05 mm) are pale greyish, and are isotropic (< 1%). Zircon (< 0.05 mm) occurs as small, subrounded fragments (< 1%). Sedimentary fragments (< 0.35 mm) are very fine to fine grained (2%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.3 mm) with minor phyllosilicates (13-15%), and porphyritic Type 3 grains (< 0.3 mm) (12%). Metamorphic grains (< 0.4 mm) (8%). Matrix consists of brown phyllosilicate and clay (8-10%), zeolite which has low birefringence and 2 cleavages (laumontite) (5%), and minor calcite (5%). As much as 25% of this sample has been removed during thin section preparation. Mineral grains, 45%; lithic fragments, 35 - 37%; matrix, 18 - 20%.

Sample 02-2-9

Micaceous litharenite: dusty, subangular to subrounded grains of quartz, biotite, muscovite, plagioclase, chlorite, zircon, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of carbonaceous material, phyllosilicate/clay, calcite, and ?silica. Quartz grains (< 0.35 mm) are monocrystalline, showing straight to undulose extinction, with quartz overgrowths, triple grain junctions, and irregular grain boundaries, rarely with inclusions (43%). Biotite is red-brown to pale yellow-brown, with pleochroism, and occurs as long, thin flakes (< 0.75 mm) or as rectangular flakes (< 0.25 mm) (8%). Muscovite flakes (< 0.4 mm) are long, thin, and colorless, with one good cleavage (2%). Plagioclase grains (< 0.2 mm) have albite twinning; average composition is An_{29} (1%). Chlorite flakes (< 0.35 mm) have green to pale green pleochroism, and wavy cleavage (< 1%). Zircon (< 0.08 mm) occurs as small subangular fragments (< 1%). Chert grains (< 0.2 mm) are medium grained (< 1%). Sedimentary fragments (< 0.26 mm) are very fine to fine grained (2%). Volcanic fragments include porphyritic Type 1 grains (< 0.3 mm) with minor phyllosilicates (5-

7%), and porphyritic Type 3 grains (< 0.25 mm) (3%). Metamorphic grains (< 0.3 mm) (4%). Carbonaceous material (1%). Matrix consists of clay (24%), minor calcite (7%), and quartz?. Mineral grains, 54%; lithic fragments, 14%; matrix, 32%.

Sample 02-2-19

Immature micaceous litharenite: subangular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, muscovite, chlorite, zircon, tourmaline, garnet, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of phyllosilicate/clay, and calcite. Quartz grains (< 0.4 mm) are monocrystalline, usually showing straight to undulose extinction, with quartz overgrowths and irregular grain boundaries (20%). Biotite flakes (< 1.2 mm) are altered, dirty red-brown pleochroism to pale yellow-brown with faint pleochroism, with distorted cleavage (7%). Plagioclase grains (< 0.35 mm) are dusty to clear, showing albite twinning; average composition is An_{25} (2%). Potassium feldspar grains (< 0.12 mm) occur with cross hatch twinning (microcline), and are rimmed with sericite (2-3%). Muscovite flakes (< 0.15 mm) are colorless, with one good cleavage (1-2%). Chlorite flakes (< 0.1 mm) have green-light green pleochroism, and wavy cleavage (< 1%). Zircon (< 0.12 mm) occurs as elongate prisms and small fragments (< 1%). Tourmaline (< 0.08 mm) shows yellow-olive pleochroism, and lacks cleavage (<1%). Garnet fragments (< 0.06 mm) are dirty greyish to colorless with very high relief, and are isotropic (< 1%). Chert grains (0.1 - 0.3 mm) are colorless to dusty, microcrystalline to medium grained (3%). Sedimentary fragments (0.2 – 4.5 mm) are dirty brown, very fine to medium grained (5%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.4 mm) commonly with phyllosilicates (10-12%), Type 2 grains (< 0.3 mm) (< 1%), and porphyritic and aphanitic

Type 3 grains (< 0.5 mm) (8-10%). Metamorphic fragments (< 0.35 mm) (3-4%). Carbonaceous debris (< 1%). Matrix consists of phyllosilicate/clay (25-30%) and calcite (6-9%). Mineral grains, 35 - 37%; lithic fragments, 26 - 31%; matrix, 32 - 39%.

Sample 02-2-23

Micaceous litharenite: subangular grains of quartz, biotite, muscovite, plagioclase, potassium feldspar, chlorite, zircon, opaques, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of calcite, silica (chalcedony), and phyllosilicate/clay. Monocrystalline quartz grains (< 0.3 mm) show straight to slight undulose extinction, with quartz overgrowths and irregular grain boundaries; sutured, and straight edge margins are common (20%). Biotite flakes (< 0.5 mm) are altered, dirty orange-brown pleochroism to pale yellow with faint pleochroism, with distorted cleavage (7%). Muscovite flakes (< 0.25 mm) are colorless, with distorted cleavage (2-3%). Plagioclase grains (< 0.1 mm) are dusty to clear, showing albite twinning; no grains allow determination of composition (2%). Potassium feldspar grains (< 0.12 mm) occur with cross hatch twinning (microcline) (2%). Chlorite flakes (< 0.15 mm) have green-colorless pleochroism, and wavy cleavage (< 1%). Zircon (< 0.08 mm) occurs as elongate prisms (< 1%). Chert grains (< 0.2 mm) are colorless to dusty, microcrystalline to fine (4%). Sedimentary fragments (< 0.2 mm) are very fine to medium grained (2%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.2 mm) with phyllosilicates (7-10%), and porphyritic Type 3 grains (< 0.2 mm) with rare phyllosilicates (5%). Metamorphic fragments (< 0.2 mm) (1-2%). Polycrystalline quartz (< 0.3 mm) (1%). Carbonaceous debris (< 1%). Matrix consists of calcite (30%), silica

(7%), and phyllocsilicate/clay (5-10%). Mineral grains, 37 - 38%; lithic fragments, 16 - 20%; matrix, 42 - 47%.

Sample 02-2-28

Immature litharenite: subangular to subrounded grains of quartz, biotite, potassium feldspar, muscovite, plagioclase, chlorite, apatite, tourmaline, garnet, chert, sedimentary fragments, volcanic fragments, and opaques in a matrix of predominately phyllosilicate/clay, and some quartz. Monocrystalline quartz grains (< 0.15 mm) usually show straight to slight undulose extinction, with irregular, dark margins, uncommonly rimmed with serecite (25%). Biotite flakes (< 0.3 mm) have dirty red-brown to pale brown pleochroism, with distorted cleavage (5%). Potassium feldspar grains (< 0.1 mm) occur with ragged boundaries and serecite in cleavage (5%). Muscovite flakes (< 0.25 mm) are colorless, with distorted cleavage (2%). Plagioclase grains (< 0.08 mm) are dusty, showing albite twinning; no grains allow determination of composition (1%). Chlorite flakes (< 0.08 mm) have green to colorless pleochroism, and wavy cleavage (< 1%). Apatite grains (< 0.05 mm) are rounded, with high relief and low birefringence (< 1%). Tourmaline (< 0.08 mm) shows yellow-olive pleochroism (<1%). Garnet fragments (< 0.08 mm) are greyish with very high relief, and are isotropic (< 1%). Chert grains (0.1 mm) are colorless to dusty, and fine grained (2-3%). Sedimentary fragments (< 0.1 mm) are fine to medium grained (4%). Volcanic fragments include porphyritic Type 1 grains (< 0.1 mm) with rare phyllosilicates (10-12%), and Type 3 grains (< 0.1 mm) without phyllosilicates (5%). Polycrystalline quartz (< 0.1 mm) occurs with undulose extinction (< 1%). Opaques occur as granular, spherical masses up to 3.5 mm in diameter, and are red on thin edges (hematite) (4%). Mineral grains, 45 - 46%; lithic fragments, 19 - 21%; matrix, 33 - 36%.

Sample 02-2-37

Immature sublitharenite: subangular to subrounded grains of quartz, biotite, potassium feldspar, plagioclase, muscovite, garnet, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of calcite, quartz, and clays. Monocrystalline quartz grains (< 2.0 mm) show straight to undulose extinction, with abundant quartz overgrowths, inclusions, sutured margins, triple grain junctions, and dark rims (44%). Biotite flakes (< 0.75 mm) have red-brown pleochroism or are bleached pale yellow, with distorted cleavage (2%). Potassium feldspar grains (< 1.25 mm) exhibit cross hatch twinning (microcline) (2%), and perthite exsolution (microperthite) (1%). Plagioclase grains (< 0.08 mm) are clear, showing albite twinning; composition obtained from only one grain, An_{24} (1%). Muscovite flakes (< 0.75 mm) are colorless, with distorted cleavage (< 1%). Garnet fragments (< 0.5 mm) are greyish with very high relief, and are isotropic (< 1%). Chert grains (0.5 mm) are dusty, and fine grained (1%). Sedimentary fragments (< 1.5 mm) are medium grained (3%). Volcanic fragments include porphyritic Type 1 grains (< 0.75 mm) with uncommon phyllosilicates (3-5%). Metamorphic fragments (< 1.0 mm) (1%). Polycrystalline quartz (< 1.25 mm) has undulose extinction (2-3%). Matrix consists of calcite (20%), quartz (12%), and clay (5-8%) Mineral grains, 51%; lithic fragments, 9 - 12%; matrix, 37 - 40%.

Sample 02-2-39

Litharenite: dirty, subangular to subrounded grains of quartz, biotite, plagioclase, muscovite, chlorite, chert, zircon, tourmaline, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of carbonaceous debris, calcite, clays, and zeolite. Quartz grains (< 0.24 mm) show straight to undulose extinction, with quartz overgrowths, inclusions of mica and apatite, sutured margins, and dark rims (25%). Biotite (< 0.25 mm) occurs predominately as large, rectangular flakes that are bleached pale yellow, with faint pleochroism, and distorted cleavage (5%). Plagioclase grains (< 0.14 mm) show albite twinning; average composition is An_{27} (1%). Muscovite flakes (< 0.22 mm) are colorless, with distorted cleavage (1%). Chlorite (< 0.18 mm) has light green pleochroism, and wavy cleavage (< 1%). Zircon (< 0.05 mm) occurs as small rounded grains (< 1%). Tourmaline (< 0.1 mm) has olive pleochroism, and lacks cleavage (< 1%). Chert grains (0.15 mm) are dusty, and microcrystalline to fine grained (4%). Sedimentary fragments (< 0.2 mm) are very fine to fine grained (5-7%). Volcanic fragments (< 0.2 mm) include aphanitic and porphyritic Type 1 grains commonly with phyllosilicates (17%), and porphyritic Type 3 grains lacking phyllosilicates (5-8%). Metamorphic fragments (< 0.3 mm) (1-2%). Opaques (< 0.3 mm) occur as granular masses, and are red on edges (hematite) (1%). Carbonaceous material (3%). Matrix consists of calcite (12-15%), clays (8-10%), and zeolite (5-7%) Mineral grains, 37 - 38%; lithic fragments, 28 - 34%; matrix, 28 - 35%.

Sample 02-2-40

Litharenite: subangular to subrounded grains of quartz, biotite, plagioclase, altered feldspar, muscovite, zircon, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of calcite, clays, and zeolite. Quartz grains (< 0.25 mm) show straight to undulose extinction, with quartz overgrowths, inclusions, sutured margins, and dark rims (25%). Biotite flakes (< 0.2 mm) are predominately bleached pale yellow, with distorted cleavage (3%). Plagioclase grains (< 0.15 mm) are dusty, showing albite twinning; average composition is An_{26} (2%). Altered feldspar (< 0.15 mm) occurs as laths or as rounded grains with an altered core that is nearly isotropic, with a rim of unaltered mineral with low birefringence (2-3%). Muscovite flakes (< 0.1 mm) are colorless, with distorted cleavage (< 1%). Zircon (< 0.02 mm) occurs as small rounded grains (< 1%). Chert grains (0.15 mm) are dusty, and microcrystalline to fine grained (4%). Sedimentary fragments (< 0.2 mm) are very fine to fine grained (5-7%). Volcanic fragments (< 0.2 mm) include aphanitic and porphyritic Type 1 grains commonly with phyllosilicates (17%), and porphyritic Type 3 grains lacking phyllosilicates (5-8%). Metamorphic fragments (< 0.3 mm) (1-2%). Opaques (< 0.3 mm) occur as granular masses, and are red on edges (hematite) (1%). Carbonaceous material (3%). Matrix consists of calcite (12-15%), clays (8-10%), and zeolite (5-7%) Mineral grains, 37 - 38%; lithic fragments, 28 - 34%; matrix, 28 - 35%.

Sample 02-3-2

Immature lithic subarkose: subangular to subrounded grains commonly rimmed with serecite of quartz, potassium feldspar, biotite, plagioclase, muscovite, garnet, tourmaline, zircon, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of brown phyllosilicate/clays and sericite. Quartz grains (< 0.75 mm) show straight to undulose extinction, with extensive quartz overgrowths, inclusions, and irregular margins (45%). Potassium feldspar grains (< 0.6 mm) exhibit sericite in cleavage, cross hatch twinning (microcline), and perthite exsolution (microperthite) (5-7%). Biotite flakes (< 0.75 mm) have red-brown to yellow-orange pleochroism, with distorted cleavage (4-5%). Plagioclase grains (< 0.35 mm) show albite twinning, and some highly altered with inclusions; no grains allow determination of composition (2%). Muscovite flakes (< 0.75 mm) are colorless, elongate, with one good cleavage (< 1%). Garnet fragments (< 0.25 mm) are greyish to pale pink, and isotropic (< 1%). Tourmaline fragments (< 0.1 mm) show olive-brown pleichroism, and lack cleavage (< 1%). Zircon (< 0.02 mm) occurs as small oval-shaped grains (< 1%). Chert grains (0.15 mm) are fine grained (1%). Sedimentary fragments (< 0.5 mm) are fine to medium grained (3%). Volcanic fragments (< 0.5 mm) include aphanitic and porphyritic Type 1 grains commonly with phyllosilicates (10%). Metamorphic fragments (< 0.3 mm) (2%). Opaques (< 0.5 mm) occur as granular masses, and are reddish (hematite) (< 1%). Matrix consists of brown phyllosilicates/clays (18-22%), and sericite (5%) Mineral grains, 58 - 61%; lithic fragments, 15%; matrix, 24 - 27%.

Sample 02-4-1

Immature litharenite: angular to subrounded grains of quartz, biotite, muscovite, plagioclase, zircon, tourmaline, garnet, apatite, chert, sedimentary fragments, and volcanic fragments, commonly with irregular grain boundaries, in a matrix of sericite and brown phyllosilicate and clays. Quartz grains (< 0.2 mm) are monocrystalline, dusty to clear, usually showing straight to slight undulose extinction, with quartz overgrowths and dark rims (30%). Biotite flakes (< 0.3 mm) are altered, with dirty red-brown pleochroism to pale yellow-brown with faint pleochroism, and distorted cleavage (5-7%). Muscovite flakes (< 0.2 mm) are colorless, with one good cleavage (1-2%). Plagioclase grains (< 0.075 mm) are dusty to clear, showing albite twinning; no grains allow determination of composition (1%). Zircon (< 0.1 mm) occurs as subrounded grains (< 1%). Tourmaline (< 0.05 mm) shows yellow-olive pleichroism, as elongate prisms or with a sub-triangular shape (< 1%). Garnet fragments (< 0.06 mm) are abundant, dirty greyish to pale pink with very high relief, and are isotropic (< 1%). Apatite grains (< 0.075 mm) have high relief and low birefringence (< 1%). Chert grains (< 0.15 mm) are dusty, and fine grained (3-4%). Sedimentary fragments (< 0.2 mm) are yellowish brown, fine to medium grained (2%). Volcanic fragments include Type 1 grains (< 0.2 mm) with slight to abundant phyllosilicate alteration (10%) and without alteration (5%), and Type 3 grains (< 0.15 mm) predominantly quartzose with few laths of plagioclase (2%). Carbonaceous debris (1-2%). Mineral grains, 40 - 44%; lithic fragments, 19%; matrix, 37 - 41%.

Sample 02-4-10

Lithic subarkose: dusty, subangular to subrounded grains of quartz, plagioclase, potassium feldspar, biotite, muscovite, amphibole, garnet, apatite, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of brown phyllosilicate/clays and chalcedony. Monocrystalline quartz grains (< 0.35 mm) show straight to undulose extinction, with quartz overgrowths, and irregular, dark margins (35%). Plagioclase grains (< 0.25 mm) show albite twinning and rare Carlsbad-albite twinning; average composition is An_{30} (6%). Potassium feldspar grains (< 0.35 mm) show crosshatch twinning (microcline), perthite exsolution (microperthite), and few grains have a very high 2V angle (orthoclase?) (4-6%). Biotite flakes (< 0.3 mm) have red-brown pleochroism, with distorted cleavage (2%). Muscovite flakes (< 0.4 mm) are colorless, and elongate, with one good cleavage (< 1%). Amphibole (<0.25 mm) has slight pale brown to greenish pleochroism, and shows two cleavages (hornblende) (< 1%). Garnet fragments (< 0.5 mm) are light grey to light pink and isotropic (1%). Apatite (< 0.2 mm) occurs as rounded grains with high relief and low birefringence (< 1%). Chert grains (0.25 mm) are fine grained (1%). Sedimentary fragments (< 0.3 mm) are fine grained (3%). Volcanic fragments (< 0.35 mm) include porphyritic Type 1 grains (8%), and porphyritic Type 3 grains lacking phyllosilicate (3%). Metamorphic fragments (< 0.35 mm) (2-3%). Polycrystalline quartz (< 0.2 mm) (< 1%). Opaques (< 0.1 mm) occur as small black grains (magnetite) (1%). Mineral grains, 50 - 52%; lithic fragments, 16-17%; matrix, 31 - 33%.

Sample 02-4-13

Lithic subarkose: dusty, subangular to moderately rounded grains of quartz, plagioclase, potassium feldspar, biotite, muscovite, garnet, zircon, apatite, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of brown phyllosilicate, clays, silica, and zeolite?. Monocrystalline quartz grains (< 1.25 mm) show straight to undulose extinction, with quartz overgrowths, and irregular margins (42-45%). Plagioclase grains (< 0.55 mm) show albite twinning, occasionally with inclusions; average composition is An_{29} (5%). Potassium feldspar grains (< 0.75 mm) show crosshatch twinning (microcline), and perthite exsolution (microperthite) (3%). Biotite flakes (< 0.5 mm) have red-brown pleochroism, with one good cleavage (< 1%). Muscovite (< 0.75 mm) occurs as colorless, long, thin flakes, with one good cleavage (< 1%). Garnet fragments (< 0.52 mm) are light grey to pink, and isotropic (< 1%). Zircon (< 0.1 mm) occurs as rounded fragments, and rarely as elongate prisms (< 1%). Apatite (< 0.08 mm) occurs as stubby prisms with high relief and low birefringence (< 1%). Chert grains (0.3 mm) are medium grained (< 1%). Sedimentary fragments (< 0.6 mm) are fine to coarse grained (3%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.75 mm) without and with minor phyllosilicate (7%), pilotaxitic Type 2 grains (< 0.5 mm) (1%), and porphyritic Type 3 grains (< 0.65 mm) lacking phyllosilicate (3%). Metamorphic fragments (< 0.5 mm) (2-3%). Polycrystalline quartz (< 0.5 mm) (1%). Opaques occur as small red masses (< 1%). Matrix consist predominately of clays and brown phyllosilicates, with minor quartz and possibly zeolite. Mineral grains, 50 - 53%; lithic fragments, 17-18%; matrix, 29 - 33%.

Sample 02-4-20

Immature sublitharenite: subangular to subrounded grains of quartz, plagioclase, potassium feldspar, biotite, garnet, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of clays. Monocrystalline quartz grains (< 1.55 mm) show straight to undulose extinction, with quartz overgrowths, inclusions up to 0.05 mm of zircon, apatite, mica, and sphene?, and irregular margins (45%). Plagioclase grains (< 0.9 mm) show albite twinning; average composition is An_{28} (3%). Potassium feldspar grains (< 1.1 mm) show crosshatch twinning (microcline), perthite exsolution (microperthite); few grains show very fine albite and pericline (crosshatch) twins (anorthoclase?) (3%). Biotite flakes (< 0.3 mm) have red-brown pleochroism, with one good cleavage (< 1%). Garnet fragments (< 0.4 mm) are light grey to light pink and isotropic (< 1%). Chert grains (0.24 mm) are medium grained (< 1%). Sedimentary fragments (< 1.5 mm) are fine to coarse grained (5%). Volcanic fragments include porphyritic Type 1 grains (< 0.5 mm) (3-4%), pilotaxitic Type 2 grains (< 0.35 mm) (< 1%), and porphyritic Type 3 grains (< 0.65 mm) lacking phyllosilicate (2%). Metamorphic fragments (< 0.5 mm) (4%). Polycrystalline quartz (< 1.3 mm, though one grain is 3.25 mm) (2%). Opaque minerals occur as small red and black masses (hematite and ?magnetite) (3-4%). Mineral grains, 54 - 55%; lithic fragments, 12 - 13%; matrix, 32 - 34%.

Sample 02-4-27

Sublitharenite: dusty, subrounded grains of quartz, plagioclase, potassium feldspar, muscovite, garnet, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of clays and silt-sized particles. Monocrystalline quartz grains (< 1.55 mm) show straight to undulose extinction, with inclusions of apatite, and mica, and irregular margins (45%). Plagioclase grains (< 0.45 mm) show albite twinning; average composition is An_{28} (2-3%). Potassium feldspar grains (< 0.4 mm) show crosshatch twinning (microcline), and perthite exsolution (microperthite) (1-2%). Muscovite flakes (< 0.3 mm) are long, thin, and colorless with one good cleavage (< 1%). Garnet fragments (< 0.35 mm) are light grey to light pink and isotropic (< 1%). Chert grains (0.24 mm) are medium grained (< 1%). Sedimentary fragments (< 0.3 mm) are medium grained (1%). Volcanic fragments include porphyritic Type 1 grains (< 0.5 mm) with minor or no phyllosilicate (2%), and pilotaxitic Type 2 grains (< 0.4 mm) (< 1%). Metamorphic fragments (< 0.55 mm) (4%). Polycrystalline quartz (< 1.05 mm) (1-2%). Opaque minerals occur as black grains (< 0.1 mm) (magnetite) and small red masses (hematite) (< 1%). Mineral grains, 48 - 50%; lithic fragments, 8 - 9%; matrix, 41 - 44%.

Sample 02-4-29

Tuffaceous litharenite: subangular grains of quartz, plagioclase, biotite, muscovite, apatite, zircon, tourmaline, sedimentary fragments, glass shards, and opaques in a matrix of very fine-grained ash and clays. Quartz grains (< 0.1 mm) are monocrystalline, and show straight to slight undulose extinction, and irregular margins (8-10%). Plagioclase grains (< 0.08 mm) show albite twinning; average composition not determined (< 1%). Biotite flakes (< 0.08 mm) have brown pleochroism (2-3%). Muscovite flakes (< 0.08 mm) are long, thin, and colorless with one good cleavage (< 1%). Apatite (< 0.04 mm) occurs as rounded or stubby grains with low birefringence (< 1%). Zircon fragments (< 0.02 mm) are subangular to rounded (< 1%). Tourmaline (< 0.04 mm) occurs as rounded grains with pale olive pleochroism, and lacks cleavage (< 1%). Sedimentary fragments (< 0.14 mm) are very fine grained (1%). Glass shards (< 0.1 mm) (30%). Opaque minerals occur as black grains (< 0.08 mm) (magnetite) and small red masses (hematite) (1-2%). Mineral grains, 10 - 13%; lithic fragments, 31%; matrix, 56 - 59%.

Sample 02-4-30

Tuffaceous litharenite: subangular to subrounded grains of quartz, plagioclase, biotite, muscovite, garnet, apatite, zircon, tourmaline, sphene, sedimentary fragments, volcanic fragments, metamorphic fragments, glass shards, and opaques in a matrix of very fine-grained ash, clays, and phyllosilicate. Quartz grains (< 0.14 mm) are monocrystalline, show dominantly straight to slight undulose extinction, with minor overgrowths and irregular margins (8-10%). Plagioclase grains (< 0.1 mm, commonly < 0.06 mm) show albite twinning; average composition not determined (< 1%). Biotite flakes (< 0.1 mm) are thin, long, and have red-brown pleochroism (< 1%). Muscovite flakes (< 0.08 mm) are long, thin, and colorless with one good cleavage (< 1%). Garnet (< 0.08 mm) is light grey, and isotropic (< 1%). Apatite (< 0.06 mm) occurs as rounded or stubby grains with low birefringence (< 1%). Zircon (< 0.03 mm) occurs as rounded grains (< 1%). Tourmaline (< 0.04 mm) occurs as rounded grains with pale olive pleochroism, and lacks cleavage (< 1%). Sphene (0.06 mm) occurs as elongate, rounded fragments with pale brown pleochroism, and very high birefringence (< 1%). Sedimentary fragments (< 0.22 mm, commonly < 0.12 mm) are very fine grained (< 1%). Volcanic fragments include porphyritic Type 1 (< 0.08 mm) (1%). Metamorphic fragments (< 0.26 mm, commonly < 0.15 mm) (1%). Glass shards (< 0.16 mm) (27%). Opaque minerals occur as black grains (< 0.05 mm) (magnetite) (< 1%). Mineral grains, 9 - 11%; lithic fragments, 29%; matrix, 60 - 62%.

Sample 02-4-32

Tuffaceous sublitharenite: angular to subrounded grains of quartz, plagioclase, potassium feldspar, biotite, amphibole, pyroxene, garnet, apatite, zircon, tourmaline, sphene, volcanic fragments, metamorphic fragments, glass shards, and opaques in a matrix of very fine-grained ash, zeolite, and clays/phyllosilicate. Quartz grains (< 0.3 mm) are monocrystalline, show dominantly straight to slight undulose extinction, with inclusions of apatite and mica, and irregular margins (27-30%). Plagioclase grains (< 0.22 mm) show albite twinning; average composition An_{27} (3%). Potassium feldspar (< 0.2 mm) show crosshatch twins (microcline) (< 1%). Biotite flakes (< 0.3 mm) have pale dirty brown pleochroism, and one good cleavage (2%). Amphibole grains (< 0.28 mm) have pale brown and deep green to brown pleochroism, and two good cleavage that form angles of approximately 60 and 120 degrees (hornblende) (< 1%). Pyroxene grains (< 0.24 mm) have pale brown pleochroism and two cleavages that are nearly perpendicular (augite) (< 1%). Garnet (< 0.15 mm) is light grey, and isotropic (< 1%). Apatite (< 0.1 mm) occurs as rounded grains or stubby prisms with low birefringence (< 1%). Zircon (< 0.06 mm) occurs as rounded grains (< 1%). Tourmaline (< 0.14 mm) occurs as rounded grains with olive pleochroism, and lacks cleavage (< 1%). Sphene (0.2 mm) has faint brown pleochroism, and very high birefringence (< 1%). Volcanic fragments include porphyritic Type 1 (< 0.32 mm) with and without phyllosilicate (7%), pilotaxitic Type 2 grains (< 0.15 mm) (< 1%), and aphanitic Type 3 grains (< 0.26 mm) with minor phyllosilicate (2%). Metamorphic fragments (< 0.28 mm) (4-5%). Glass shards (< 0.25 mm) (10%). Opaque grains (< 0.12 mm) are black (magnetite) and reddish (hematite) (< 1%). Matrix ash and clays/phyllosilicate are difficult to differentiate from one another (35-36%); zeolite has very weak birefringence (analcite?) (11%). Mineral grains, 34%; lithic fragments, 23 - 24%; matrix, 46 - 47%.

Sample 02-4B-1

<u>Mudstone:</u> light pinkish brown, with mud sized particles of quartz, plagioclase, potassium feldspar, mica, zircon, tourmaline, and opaques set in a clay matrix.

Sample 02-4B-4

<u>Lithic subarkose:</u> subangular to subrounded grains of quartz, potassium feldspar, plagioclase, biotite, amphibole, garnet, zircon, tourmaline, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of clays, silica, and zeolite. Monocrystalline quartz grains (< 1.75 mm) show straight to undulose extinction, with quartz overgrowths, straight edge contacts, irregular grain boundaries, and dark rims (37-40%). Potassium feldspar (< 1.5 mm) are dusty, rarely with inclusions, showing crosshatch twinning (microcline), perthite exsolution (microperthite), and grains with a very high 2V angle (orthoclase?) (10%). Plagioclase grains (< 0.4 mm) show albite twinning, and some are being altered; average composition is An_{29} (5%). Biotite flakes (< 0.35 mm) have red-brown pleochroism, with distorted cleavage (1%). Amphibole (< 0.2 mm) has green-brown pleochroism, and two good cleavages (hornblende) (< 1%). Garnet

fragments (< 1.25 mm) are pale pinkish, some with inclusions of quartz?, and are isotropic (< 1%). Zircon (< 0.2 mm) occurs as elongate prisms (< 1%). Tourmaline (< 0.5 mm) shows green-brown pleochroism, and lacks cleavage (< 1%). Sedimentary fragments (< 0.6 mm) are fine to medium grained (4%). Volcanic fragments include porphyritic Type 1 grains (< 0.6 mm) (2%), Type 2 grains (< 0.45 mm) (< 1%), and aphanitic and porphyritic Type 3 grains (< 0.5 mm) lacking phyllosilicate (2%). Metamorphic fragments (< 0.75 mm) are schistose, as well as few grains of quartz with unaligned mica and apatite? inclusions (5%). Polycrystalline quartz (< 1.0 mm) (2%). Opaques (< 0.1 mm) occur as small black grains (magnetite) (< 1%). Matrix consists of clays (10%), quartz (8-10%), very fibrous chalcedony (6-7%), and zeolite with low birefringence; one good and one poor cleavage (laumontite) (5%). Mineral grains, 53 - 56%; lithic fragments, 15%; matrix, 29 - 32%.

Sample 02-4B-6

Tuffaceous litharenite: angular to subrounded grains of quartz, plagioclase, potassium feldspar, biotite, muscovite, apatite, zircon, sedimentary fragments, volcanic fragments, glass shards, and opaques in a matrix of mostly irresolvable material (ash) and clays, and silica (chalcedony). Quartz grains (< 0.2 mm) are monocrystalline, with undulose extinction, and irregular grain boundaries (10-12%). Plagioclase grains (< 0.2 mm) show albite twinning; average composition is An_{38} (3-4%). Potassium feldspar (< 0.2 mm) show crosshatch twinning (microcline), and perthite exsolution (microperthite) (2-3%). Biotite flakes (< 0.1 mm) have red-brown pleochroism, with distorted cleavage (3%). Muscovite flakes (< 0.1 mm) are colorless and have one good cleavage (< 1%). Apatite grains (< 0.075 mm) have high relief and low birefringence (< 1%). Zircon (< 0.05 mm)

(< 1%). Sedimentary fragments (< 0.1 mm) are medium grained (< 1%). Volcanic fragments include porphyritic Type 3 grains (< 0.15 mm) (1%), and Pumice (< 0.15) (1%). Glass shards (< 0.2 mm) (25%). Opaques (< 0.05 mm) occur as small black grains (magnetite) (1%), and granular reddish brown bodies (hematite?) (3%). Mineral grains, 47 - 51%; lithic fragments, 2 - 3%; matrix, 46 - 51%.

Sample 02-4B-9

Immature lithic subarkose: subangular to subrounded grains of quartz, potassium feldspar, plagioclase, biotite, muscovite, amphibole, garnet, zircon, tourmaline, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix dominated by clays, with some chalcedony, and zeolite. Monocrystalline quartz grains (< 1.0 mm) show straight to undulose extinction, with quartz overgrowths, and irregular grain boundaries (42%). Potassium feldspar grains (< 0.7 mm) are dusty, and show crosshatch twinning (microcline), and perthite exsolution (microperthite) (8%). Plagioclase grains (< 0.5 mm) are dusty, and show albite twinning; average composition is An_{28} (3%). Biotite flakes (< 0.15 mm) are dirty brown with slight pleochroism, and distorted cleavage (< 1%). Muscovite flakes (< 0.5 mm) are colorless, thin and elongate, with one good cleavage (< 1%). Amphibole (< 0.3 mm) has green-brown pleochroism, and two good cleavages (hornblende) (< 1%). Garnet fragments (< 1.0 mm) are pale pinkish, and isotropic (1-2%). Zircon (< 0.04 mm) occurs as small subrounded grains (< 1%). Tourmaline (< 0.25 mm) shows strong greenish-olive pleochroism, and lacks cleavage (< 1%). Sedimentary fragments (< 0.8 mm) are very fine to medium grained (2-3%). Volcanic fragments include porphyritic Type 1 grains (< 1.25 mm) with phenocrysts of quartz up to 0.25 mm in size (5%), Type 2 grains (< 0.4 mm) (< 1%), and porphyritic

Type 3 grains (< 0.5 mm) dominated by plagioclase, with little phyllosilicate (2%). Metamorphic fragments (< 0.4 mm) (1%). Polycrystalline quartz (< 1.0 mm) (2%). Opaques (< 0.2 mm) are black (magnetite) (< 1%). Mineral grains, 54 - 55%; lithic fragments, 12 - 13%; matrix, 32 - 34%.

Sample 02-5-1

Immature litharenite: subangular to subrounded grains of quartz, potassium feldspar, plagioclase, biotite, muscovite, chlorite, garnet, zircon, tourmaline, apatite, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of clays, zeolite, and quartz. Monocrystalline quartz grains (< 1.0 mm) show straight to undulose extinction, with quartz overgrowths, irregular grain boundaries, and dark rims (27-30%). Potassium feldspar grains (< 0.5 mm) are dirty to colorless, and show crosshatch twinning (microcline), and perthite exsolution (microperthite) (5%). Plagioclase grains (< 0.4 mm) show albite twinning, and are commonly altered (by zeolite); alteration inhibits determination of composition (2%). Biotite flakes (< 0.2 mm) are altered pale brown, to red-brown with pleochroism, and have distorted cleavage (1-2%). Muscovite flakes (< 0.2 mm) are colorless with one good cleavage (1%). Chlorite flakes (< 0.15 mm) have green to pale yellow pleochroism, and wavy cleavage (< 1%). Garnet fragments (< 0.6 mm) are pale pinkish to pale grey, and isotropic (< 1%). Zircon (< 0.06 mm) occurs as small prisms (< 1%). Tourmaline (< 0.075 mm) shows strong olive-green pleochroism, and lacks cleavage (< 1%). Apatite (< 0.04 mm) has high relief and low birefringence (< 1%). Chert grains (< 0.4 mm) are dusty, and fine grained (< 1%). Sedimentary fragments (< 0.4 mm) are fine grained (1%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.5 mm) with and without phyllosilicate (10%), Type 2 grains (< 0.45 mm) (1%), and porphyritic Type 3 grains (< 0.45 mm) dominated by quartz, with minor phyllosilicate (5%). Metamorphic fragments (< 1.0 mm) (1%). Polycrystalline quartz (< 0.35 mm) (< 1%). Opaques (< 0.2 mm) are black (magnetite) (< 1%). Matrix consists of clays (22-25%), zeolite with low birefringence and two cleavages (laumontite) (13%), and quartz (7%). Mineral grains, 37 - 40%; lithic fragments, 18%; matrix, 42 - 45%.

Sample 02-5-4

Immature litharenite: subangular to subrounded grains of quartz, biotite, muscovite, plagioclase, potassium feldspar, chlorite, zircon, apatite, chert, sedimentary fragments, volcanic fragments, and opaques in a matrix of phyllosilicate/clays, and carbonaceous debris. Quartz grains (< 0.15 mm) are monocrystalline, and show straight to undulose extinction, with irregular grain boundaries (25%). Biotite flakes (< 0.5 mm) have brown to pale brown pleochroism, and distorted cleavage (5-7%). Muscovite (< 0.4 mm) occurs as thin, long, colorless flakes with one good cleavage (2%). Plagioclase grains (< 0.15 mm) are dusty, and show albite and rare Carlsbad-albite twinning; average composition is An_{32} (2-3%). Potassium feldspar grains (< 0.1 mm) have perthite exsolution (microperthite) (1%). Chlorite flakes (< 0.08 mm) have green to pale green pleochroism, and wavy cleavage (< 1%). Zircon (< 0.06 mm) occurs as small rounded grains (< 1%). Apatite grains (< 0.08 mm) are abundant and have high relief and low birefringence (< 1%). Chert grains (< 0.15 mm) are dusty, and fine grained (2-3%). Sedimentary fragments (< 0.15 mm) are fine grained (3-5%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.1 mm) with and without phyllosilicate (12%), and porphyritic Type 3 grains (< 0.1 mm) with minor phyllosilicate (3-5%). Carbonaceous material (5%). Opaques (< 0.06 mm) are black (magnetite) (< 1%). Mineral grains, 37 - 41%; lithic fragments, 18 - 22%; matrix, 37 - 45%.

Sample 02-5-8

Immature litharenite: dirty, subangular to subrounded grains of quartz, biotite, altered feldspar, plagioclase, muscovite, chlorite, garnet, zircon, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of phyllosilicate/clays, and silica. Monocrystalline quartz grains (< 0.5 mm) show straight to undulose extinction, with quartz overgrowths, and dark, irregular grain boundaries (25%). Biotite flakes (< 0.5 mm) are dirty brown to pale yellowish, with pleochroism, and have distorted cleavage (3-4%). Altered feldspar grains (< 0.3 mm) are dirty, commonly with a core altered to nearly isotropic material (zeolite?), and a rim with low birefringence; other grains have low birefringence, 2 sets of fine twin lamellae at 90 degrees, and are biaxial, and have been interpreted to be some variety of feldspar (3-4%). Plagioclase grains (< 0.35 mm) show albite and rare Carlsbad-albite twinning, and commonly appear to be undergoing alteration; no grains allow determination of composition (2%). Muscovite flakes (< 0.2 mm) are colorless with one good cleavage (< 1%). Chlorite flakes (< 0.1 mm) have green to pale green pleochroism, and wavy cleavage (< 1%). Garnet fragments (< 0.08 mm) are pale greyish, and isotropic (< 1%). Zircon (< 0.04 mm) occurs as small, subrounded grains (< 1%). Sedimentary fragments (< 0.35 mm) are fine to medium grained (4%). Volcanic fragments include porphyritic Type 1 grains (< 0.4 mm) with minor phyllosilicate (15%), pilotaxitic Type 2 grains (< 0.3 mm) (2%), and porphyritic Type 3 grains (< 0.4 mm) rarely with phyllosilicate (7%). Polycrystalline quartz (< 0.3 mm)

(3%). Opaques (< 0.06 mm) are black (magnetite) (< 1%). Mineral grains, 33 - 35%; lithic fragments, 31%; matrix, 34 - 36%.

Sample 02-5-12

Immature litharenite: dirty, subangular to subrounded grains of quartz, biotite, potassium feldspar, plagioclase, muscovite, garnet, zircon, apatite, tourmaline, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of carbonaceous material, phyllosilicate/clays, and silica. Monocrystalline quartz grains (< 0.3 mm) show straight to undulose extinction, with quartz overgrowths, and dark, irregular grain boundaries (35%). Biotite flakes (< 0.3 mm) are dirty brown to pale brown, with pleochroism, and have distorted cleavage (4%). Potassium feldspar grains (< 0.15 mm) show crosshatch twinning (microcline) (2%). Plagioclase grains (< 0.2 mm) show albite twinning; average composition is An_{32} (2%). Muscovite (< 0.3 mm) occurs as colorless, long, thin flakes with one good cleavage (1%). Garnet fragments (< 0.1 mm) are pale greyish, and isotropic (< 1%). Zircon (< 0.04 mm) occurs as subrounded grains, or rarely as elongate prisms (< 1%). Apatite grains (0.08) have high relief and low birefringence (< 1%). Tourmaline (< 0.1 mm) has olive to blue green pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.1 mm) are very fine grained (1%). Sedimentary fragments (< 0.35 mm) are very fine to fine grained (1%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.3 mm) without and with minor phyllosilicates (12%), and porphyritic Type 3 grains (< 0.2 mm) rarely with phyllosilicate (5%). Metamorphic fragments (< 0.25 mm) (3-4%). Polycrystalline quartz (< 0.3 mm) (2%). Opaques (< 0.08 mm) are black (magnetite), and reddish (hematite) (< 1%).

Carbonaceous material (4%). Mineral grains, 46%; lithic fragments, 23 - 24%; matrix, 30 - 31%.

Sample 02-5-15

Immature litharenite: dirty, subangular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, muscovite, chlorite, apatite, tourmaline, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of carbonaceous material, phyllosilicate/clays, and silica. Quartz grains (< 0.25 mm) are monocrystalline, and show straight to undulose extinction, with dark, irregular grain boundaries (30%). Biotite flakes (< 0.35 mm) are dirty red-brown to pale brown, with pleochroism, and have distorted cleavage (5%). Plagioclase grains (< 0.15 mm) show albite twinning; average composition is An_{26} (2-3%). Potassium feldspar grains (< 0.15 mm) show rare Carlsbad twin (orthoclase?) (1%). Muscovite flakes (< 0.2 mm) are colorless with one good cleavage (< 1%). Apatite grains (0.08) have high relief and low birefringence (< 1%). Tourmaline (< 0.08 mm) has blue-green pleochroism, and lacks cleavage (< 1%). Sedimentary fragments (< 0.3 mm) are fine to medium grained (3%). Volcanic fragments include porphyritic Type 1 grains (< 0.25 mm) with minor phyllosilicates (10-12%), pilotaxitic Type 2 grains (< 0.2 mm) (< 1%), and aphanitic Type 3 grains (< 0.2 mm) without and with phyllosilicate (8%). Metamorphic fragments (< 0.25 mm) (3%). Opaques (< 0.02 mm) are black (magnetite) (< 1%). Carbonaceous material (3%). Matrix consists of clays, sericite, and quartz. Mineral grains, 38 - 39%; lithic fragments, 21 - 23%; matrix, 38 - 44%.

Sample 02-5-20

Immature litharenite: dirty, angular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, tourmaline, zircon, garnet, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of carbonaceous material, phyllosilicate/clays, and ?zeolite. Monocrystalline quartz grains (< 0.35 mm) show straight to undulose extinction, with irregular grain boundaries (25%). Biotite (< 0.5 mm) occurs as very dirty, long, thin flakes with red-brown pleochroism that is often obscured by their dirty nature, and distorted cleavage (5%). Plagioclase grains (< 0.3 mm) show albite and rare Carlsbad-albite twinning; average composition is An_{29} (2%). Potassium feldspar grains (< 0.2 mm) show cleavage, and many grains have an altered core of nearly isotropic material (1%). Tourmaline (< 0.15 mm) has olive to blue pleochroism, and lacks cleavage (< 1%). Zircon (< 0.1 mm) occurs as elongate prisms (< 1%). Garnet fragments (< 0.08 mm) are pale greyish, and isotropic (< 1%). Chert grains (< 0.1 mm) are fine to medium grained (1%). Sedimentary fragments (< 0.3 mm) are fine to medium grained (3%). Volcanic fragments include porphyritic Type 1 grains (< 0.3 mm, one grain is 0.7 mm) without phyllosilicates (12%), trachytic Type 2 grains (0.25 mm) (< 1%), porphyritic Type 3 grains (< 0.3 mm) rarely with phyllosilicate (5%), and extremely fine grained Type 3 grains without phyllosilicate (5%). Metamorphic fragments (< 0.35 mm) (3-4%). Polycrystalline quartz (< 0.25 mm) (3%). Opaques (< 0.04 mm) are black (magnetite) (< 1%). Carbonaceous material (3%). Matrix consists of grains which are smashed around others and appear to be clay-rich, clays, and a nearly isotropic, very fine material (zeolite?) (2-3%). Mineral grains, 34%; lithic fragments, 31 - 32%; matrix, 34 - 35%.

Sample 02-5-22

<u>Sublitharenite:</u> dusty to clear, subangular to subrounded grains of quartz, potassium feldspar, plagioclase, biotite, garnet, tourmaline, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of phyllosilicate/clays, silica, and iron oxides. Quartz grains (< 1.25 mm) are monocrystalline and show straight to undulose extinction, with extensive quartz overgrowths, and irregular grain boundaries (45%). Potassium feldspar grains (< 0.6 mm) show well developed crosshatch twinning (microcline), and perthite exsolution (microperthite) (3%). Plagioclase grains (< 0.5 mm) show albite twinning; average composition from three grains is An_{30} (1%). Biotite (< 0.25 mm) occurs as dirty flakes with red-brown pleochroism and distorted cleavage (1%). Garnet fragments (< 0.3 mm) are pale pink to pale grey, and isotropic (< 1%). Tourmaline (< 0.2 mm) has blue to green pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.35 mm) are fine to medium grained (1%). Sedimentary fragments (< 0.8 mm) are fine to medium grained (7%). Volcanic fragments include porphyritic Type 1 grains (< 0.7 mm) with minor phyllosilicate (7%), pilotaxitic Type 2 grains (0.3 mm) (< 1%), and porphyritic Type 3 grains (< 0.55 mm) with minor phyllosilicate (3%). Metamorphic fragments (< 0.6 mm) (4%). Opaques (< 0.25 mm) are black (magnetite) (< 1%). Matrix consists of clays (17%), quartz (8%), and reddish iron oxides (3%). Mineral grains, 51%; lithic fragments, 21%; matrix, 28%.

Sample 02-5-23

<u>Immature sublitharenite:</u> dusty, subangular to subrounded grains of quartz, potassium feldspar, biotite, plagioclase, garnet, zircon, tourmaline, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of carbonaceous material, white and brown phyllosilicates, and clays. Quartz grains (< 0.4 mm) are monocrystalline

and show straight to undulose extinction, with quartz overgrowths, and irregular grain boundaries (40%). Potassium feldspar grains (< 0.25 mm) show crosshatch twinning (microcline) (3%). Biotite (< 0.5 mm) occurs as altered, dirty red-brown flakes with faint pleochroism and distorted cleavage (3%). Plagioclase grains (< 0.4 mm) show albite twinning; average composition is An_{30} (1%). Garnet fragments (< 0.12 mm) are pale pink to grey, and isotropic (< 1%). Zircon (< 0.15 mm) occurs as elongate or rounded prisms (< 1%). Tourmaline (< 0.2 mm) has olive pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.25 mm) are fine to medium grained (1%). Sedimentary fragments (< 0.3 mm) are fine to medium grained (4%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.35 mm) without and with minor phyllosilicate (7%), and aphanitic Type 3 grains (< 0.35 mm) with minor phyllosilicate (1%). Metamorphic fragments (< 0.3 mm) (2%). Opaque grains (< 0.04 mm) are black (magnetite) (< 1%). Carbonaceous material (2%). Matrix consists of white phyllosilicate (sericite), brown phyllosilicate (biotite), and clays. Mineral grains, 48%; lithic fragments, 14%; matrix, 38%.

Sample 02-6-1

Sublitharenite: clear to dusty, subrounded grains of quartz, potassium feldspar, plagioclase, garnet, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of calcite. Monocrystalline quartz grains (< 0.8 mm) show mostly undulose extinction, with quartz overgrowths, inclusions of apatite and zircon, and irregular grain boundaries (35%). Potassium feldspar grains (< 0.65 mm) show crosshatch twinning (microcline) (3%). Plagioclase grains (< 0.7 mm) show albite twinning; average composition is An_{27} (2%). Garnet fragments (< 0.52 mm) are pale pink to light grey, and isotropic (< 1%). Sedimentary fragments (< 0.5 mm) are coarse grained

(2%). Volcanic fragments include porphyritic Type 1 grains (< 0.46 mm) commonly with large phenocrysts (4%), and porphyritic Type 3 grains (< 0.4 mm) (1-2%). Metamorphic fragments (< 0.48 mm) (2%). Polycrystalline quartz (< 0.48 mm) (< 1%). Matrix consists of secondary calcite, which is commonly replacing other mineral grains. Mineral grains, 40%; lithic fragments, 9 - 10%; matrix, 50 - 51%.

Sample 02-6-5

Sublitharenite: dusty to dirty, subangular to subrounded grains of quartz, plagioclase, biotite, muscovite, garnet, zircon, tourmaline, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of silty material, brown phyllosilicates, and clays. Quartz grains (< 0.16 mm) are monocrystalline and show straight to undulose extinction, with quartz overgrowths, triple grain junctions, straight edge grain boundaries, inclusions of mica, zircon, and apatite, and dark rims (55%). Plagioclase grains (< 0.08 mm) show albite twinning; average composition not determined (1%). Biotite (< 0.24 mm) occurs as pale yellowish-brown flakes with faint pleochroism and distorted cleavage (1%). Muscovite (< 0.2 mm) occurs as colorless, long, thin flakes with one good cleavage (1%). Garnet fragments (< 0.16 mm) are light grey, and isotropic (< 1%). Zircon (< 0.06 mm) occurs as rounded oval shaped grains (< 1%). Tourmaline (< 0.06 mm) has olive pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.18 mm) are medium grained (< 1%). Sedimentary fragments (< 0.3 mm) are very fine-grained (1%). Volcanic fragments include porphyritic Type 1 grains (< 0.16 mm) without phyllosilicate (5-7%). Metamorphic fragments (< 0.18 mm) (3%). Opaque grains (< 0.06 mm) are black (magnetite) (< 1%). Mineral grains, 58%; lithic fragments, 9 - 11%; matrix, 31 - 33%.

Sample 02-6-6

Lithic subarkose: clear to dusty, subrounded grains of quartz, plagioclase, potassium feldspar, amphibole, pyroxene, garnet, zircon, apatite, tourmaline, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of zeolite, silica, and minor phyllosilicate/clays. Quartz grains (up to 1.5 mm, commonly < 1.2 mm) are monocrystalline and show straight to undulose extinction, with quartz overgrowths, inclusions of zircon and apatite, and irregular, dark rims (40%). Plagioclase grains (< 0.8 mm) show albite twinning; average composition An_{30} (4%). Potassium feldspar (< 0.52 mm) shows crosshatch twinning (microcline), and perthite exsolution (microperthite) (3-4%). Amphibole grains (< 0.3 mm) have brown to tan pleochroism, and two good cleavages that form angles of 60, and 120 degrees (hornblende) (< 1%). Pyroxene grains (< 0.28 mm) have pale green pleochroism, and two cleavages that are nearly perpendicular (augite) (< 1%). Garnet fragments (< 0.35 mm) are light grey to light pink and isotropic (< 1%). Zircon (< 0.1 mm) occurs as angular fragments or rounded oval shaped grains (< 1%). Apatite (< 0.08) occurs as stubby rounded grains, orrarely as hexagonal prisms (< 1%). Tourmaline (< 0.06 mm) has olive pleochroism, and lacks cleavage (< 1%). Sedimentary fragments (< 0.68 mm) are medium grained (< 1%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.52 mm) without phyllosilicate (3-4%), and porphyritic Type 3 grains (< 0.3 mm) (1%). Metamorphic fragments (< 0.46 mm) (1%). Opaque grains (< 0.06 mm) are black (magnetite) (< 1%). Matrix consists of ?two varieties of zeolite- one with two cleavages and first order yellow birefringence (laumontite) and another with one parting/cleavage and low grey birefringence (stilbite?), quartz, and a small amount of fine clays and/or phyllosilicate. Mineral grains, 48%; lithic fragments, 5 - 6%; matrix, 46 - 47%.

Sample 02-7-5

Tuffaceous siltstone: subangular to subrounded grains of quartz, plagioclase, biotite, muscovite, garnet, apatite, zircon, tourmaline, volcanic fragments, metamorphic fragments, glass shards, and opaques in a matrix of very fine-grained ash and clays. Quartz grains (up to 0.14 mm, commonly < 0.08 mm) are monocrystalline, and show straight to slight undulose extinction, uncommonly with irregular margins (8%). Plagioclase grains (< 0.08 mm) show albite twinning; average composition not determined (< 1%). Biotite flakes (< 0.12 mm) are thin, with red-brown pleochroism (2%). Muscovite flakes (< 0.1 mm) are thin and colorless, with birds-eye extinction (1%). Garnet fragments (< 0.07 mm) are light grey, and isotropic (< 1%). Apatite (< 0.04 mm) occurs as stubby grains with low birefringence (< 1%). Zircon (< 0.06 mm) occurs as rounded grains (< 1%). Tourmaline (< 0.06 mm) shows olive pleochroism, and lacks cleavage (< 1%). Volcanic fragments (< 0.1 mm) include porphyritic Type 1 grains (1%). Metamorphic fragments (< 0.08 mm) (< 1%). Glass shards (< 0.14 mm) (25%). Opaque minerals occur as black grains (up to 0.06 mm, commonly < 0.02 mm) (magnetite) and small reddish masses (< 1%). Mineral grains, 11%; lithic fragments, 26%; matrix, 63%.

Sample 02-7-6

Tuffaceous siltstone: subangular grains of quartz, plagioclase, potassium feldspar, biotite, muscovite, amphibole, garnet, apatite, zircon, sedimentary fragments, metamorphic fragments, glass shards, and opaques in a matrix of very fine-grained ash and clays. Quartz grains (< 0.12 mm) are monocrystalline, and show straight to slight undulose extinction, uncommonly with irregular margins (15%). Plagioclase grains (< 0.1 mm) show albite twinning; average composition is An_{39} (1%). Potassium feldspar (< 0.1 mm) shows perthite exsolution (< 1%). Biotite flakes (< 0.2 mm) are thin and long, with red-brown pleochroism (< 1%). Muscovite flakes (< 0.15 mm) are long, thin, and colorless with one good cleavage (< 1%). Amphibole grains (< 0.06 mm) show green to brown pleochroism, and appear to have one good and one poor cleavage (hornblende?). Garnet fragments (< 0.06 mm) are light grey, and isotropic (< 1%). Apatite (< 0.04 mm) occurs as rounded or stubby grains with low birefringence (< 1%). Zircon (< 0.08 mm) occurs as elongate prisms, or as rounded grains (< 1%). Sedimentary fragments (< 0.15 mm) are fine grained (< 1%). Metamorphic fragments (< 0.18 mm) (< 1%). Glass shards (< 0.14 mm) (27-30%). Opaque minerals occur as black grains (< 0.04 mm) (magnetite) (< 1%). Mineral grains, 16%; lithic fragments, 28 - 30%; matrix, 54 - 56%.

Sample 02-8-6

Immature litharenite: dusty to dirty, subangular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, muscovite, chlorite, zircon, apatite, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments in a matrix of carbonaceous material, phyllosilicates/clays, and silica. Quartz grains (< 0.4 mm) are monocrystalline and show straight to undulose extinction, with irregular grain boundaries and inclusions of mica and apatite? (17-20%). Biotite flakes (< 0.35 mm) are red-brown to pale brown, pleochroic, and have distorted cleavage (3%). Plagioclase grains (< 0.4 mm) show albite and rare Carlsbad-albite twinning; average composition is An_{32} (2%). Potassium feldspar grains (< 0.2 mm) show crosshatch twinning (microcline) (< 1%). Muscovite (< 0.25 mm) occurs as long, thin, colorless flakes with one good cleavage (< 1%). Chlorite flakes

(< 0.25 mm) have light green pleochroism, and wavy cleavage (< 1%). Zircon (< 0.04 mm) occurs as small angular fragments (< 1%). Apatite (< 0.06 mm) occurs as slender or stubby prisms, usually as inclusions in quartz (< 1%). Chert grains (< 0.25 mm) are fine to medium grained (1%). Sedimentary fragments (< 0.35 mm) are fine to medium grained (3%). Volcanic fragments include aphanitic and porphyritic Type 1 grains (< 0.3 mm) with and without phyllosilicate (17%), trachytic and pilotaxitic Type 2 grains (< 0.4 mm) (4%), and porphyritic Type 3 grains (< 0.25 mm) with minor phyllosilicate (7%). Metamorphic fragments (< 0.4 mm) occur as schistose fragments, as well as fragments containing mostly stretched and flattened quartz with minor or no phyllosilicates (quartzite?) (7%). Opaques (< 0.06 mm) are black (magnetite) (< 1%). Carbonaceous material (1%). Matrix consists of phyllosilicates and clays (31-32%), and quartz and chalcedony (5-7%). Mineral grains, 23 - 26%; lithic fragments, 38%; matrix, 36 - 39%.

Sample 02-8-15

Litharenite: dusty, subangular to subrounded grains of quartz, biotite, plagioclase, potassium feldspar, muscovite, chlorite, garnet, zircon, tourmaline, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of carbonaceous material, calcite, and minor clays. Monocrystalline quartz grains (< 0.35 mm) show straight to undulose extinction, with irregular grain boundaries, and may contain aligned and unaligned inclusions (25%). Biotite flakes (< 0.5 mm) are dirty, red-brown to pale brown, pleochroic, and have distorted cleavage (2-3%). Plagioclase grains (< 0.25 mm) show albite twinning, rarely with inclusions; average composition is An_{29} (2%). Potassium feldspar grains (< 0.3 mm) have crosshatch twinning (microcline), or are altered with an isotropic core (2%). Muscovite (< 0.4 mm) occurs as long, thin, colorless flakes with one good cleavage (< 1%). Chlorite flakes (< 0.45 mm) have pale green pleochroism, and wavy cleavage (< 1%). Garnet (< 0.25 mm) is light grey to pale pink, and isotropic (< 1%). Zircon (< 0.1 mm) occurs as small subrounded grains (< 1%). Tourmaline (< 0.1 mm) shows olive-blue pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.35 mm) are fine to medium grained (< 1%). Sedimentary fragments (< 0.35 mm, one grain is 0.65 mm) are fine to coarse grained (4%). Volcanic fragments include porphyritic Type 1 grains (< 0.3 mm), with minor or without phyllosilicate (7-8%), trachytic and pilotaxitic Type 2 grains (< 0.4 mm) (< 1%), and porphyritic Type 3 grains (< 0.25 mm) with minor phyllosilicate (2-3%). Metamorphic fragments (< 0.25 mm) (2%). Polycrystalline quartz (< 0.2 mm) (< 1%). Opaques (< 0.15 mm) are black (magnetite), and reddish (hematite) (< 1%). Carbonaceous material (< 1%). Mineral grains, 31 - 32%; lithic fragments, 15 - 17%; matrix, 51 - 54%.

Sample 02-8-16

Sublitharenite: dusty, subangular to subrounded grains of quartz, plagioclase, potassium feldspar, biotite, zircon, chert, sedimentary fragments, volcanic fragments, and metamorphic fragments, all commonly undergoing replacement by calcite cement. Quartz grains (< 0.65 mm) show straight to slight undulose extinction (22 -25%). Plagioclase grains (< 0.3 mm) show albite twinning, and rarely contain inclusions; average composition obtained from two grains, An_{31} (1%). Potassium feldspar grains (< 0.5 mm) have crosshatch twinning (microcline), and perthite exsolution (1-2%). Biotite flakes (< 0.35 mm) are pale brown, with slight pleochroism, and show one good cleavage (< 1). Zircon grains (< 0.15 mm) are oval shaped to elongate prisms (< 1%). Chert grains (< 0.4 mm) are fine grained (< 1%). Sedimentary fragments (< 0.5 mm) are medium grained

(4%). Volcanic fragments include porphyritic Type 1 grains (< 0.45 mm), with and without phyllosilicate (5%), pilotaxitic Type 2 grains (< 0.35 mm) (< 1%), and porphyritic Type 3 grains (< 0.3 mm) with minor phyllosilicate (1%). Metamorphic fragments (< 0.5 mm) (2%). Mineral grains, 24 - 28%; lithic fragments, 12%; matrix, 60 - 64%.

Sample 02-8-19

Immature litharenite: dirty, subangular to subrounded grains of quartz, biotite, plagioclase, altered feldspar, muscovite, chlorite, garnet, zircon, apatite, tourmaline, chert, sedimentary fragments, volcanic fragments, metamorphic fragments, and opaques in a matrix of carbonaceous material, clays/phyllosilicates, and quartz. Quartz grains (< 0.25 mm) show straight to slight undulose extinction, many with unaligned inclusions, minor overgrowths, and irregular margins (35%). Biotite flakes (< 0.4 mm) are red-brown to pale brown, with pleochroism, and one good cleavage (5%). Plagioclase grains (< 0.2 mm) show albite twinning, and rarely contain inclusions; average composition obtained from two grains, An_{30} (2%). Altered feldspar grains (< 0.2 mm) have an isotropic, altered core (zeolite?), and a rim with low birefringence (1%). Garnet fragments (< 0.08 mm) are light grey, and isotropic (< 1%). Zircon grains (< 0.1 mm) are rounded (< 1%). Apatite (< 0.06 mm) occurs as stubby prisms or rounded fragments with low birefringence (< 1%). Tourmaline (< 0.1 mm) shows olive pleochroism, and lacks cleavage (< 1%). Chert grains (< 0.25 mm) are fine grained (1%). Sedimentary fragments (< 0.25 mm) are medium grained (3%). Volcanic fragments include porphyritic Type 1 grains (< 0.3 mm), with minor phyllosilicate (8%), pilotaxitic Type 2 grains (< 0.2 mm) (1-2%), and porphyritic Type 3 grains (< 0.25 mm) without and with minor phyllosilicate

(3%). Metamorphic fragments (< 0.25 mm) (5%). Opaque grains are black (magnetite) (< 1%). Carbonaceous material (2%). Mineral grains, 44%; lithic fragments, 20 - 21%; matrix, 35 - 36%.